MOVEMENT OF SHALLOW GROUNDWATER IN THE PERRYVILLE KARST AREA, SOUTHEASTERN MISSOURI

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ABSTRACT

Ordovician and Mississippian carbonate rocks outcropping in a belt along the eastern flank of the Ozark uplift in southeastern Missouri have been intensly karstified. Perry County lies roughly in the center of this karst belt and contains more than 576 known caves, most of them in several large sinkhole plains underlain by the middle Ordovician Plattin Formation and Joachim Dolomite. The city of Perryville (population 7,343) lies along the southern edge of the Perryville sinkhole plain. Most of the city plus and adjoining area of 16 mi² is internally drained through sinkholes and extensive cave systems.

The city of Perryville no longer uses the karst drainage system for sewage disposal, but still relies on it for stormwater disposal. Vertical pipes with trash racks, installed in numerous sinkholes in the city to keep the throats of the sinks open, allow runoff from storms to enter the subsurface more rapidly and decrease local sinkhole flooding. To facilitate drainage, runoff entering slow-draining sinkholes is channeled to more open sinks. A hydrogeologic study was undertaken to determine recharge areas of local springs, to help avoid changing recharge patterns by diverting storm runoff from the recharge area of one spring to that of another, and to be able to predict the effects of hazardous-material spills in the karst area.

Numerous springs and karst resurgences occur along the two major surface drainages bounding the Perryville sinkhole plain, Blue Spring Branch and Cinque Hommes Creek, and are recharged from the sinkhole plain. Groundwater outflow comes from two types of outlets: springs, which are generally perennial and discharge cave stream base flows, and karst resurgences, which are overflow outlets of cave streams and typically function only after intense precipitation. Spring discharges vary greatly, depending on local precipitation. A given spring may have peak discharges 100 times greater than low-flow discharges.

Fluorescein and Rhodamine WT dyes were used to help define recharge areas of local springs. A scanning spectrofluorometer used for dye detection reduced interference from extraneous fluorescent materials and allowed simultaneous use of two fluorescent tracing agents. Twenty dye traces, with injection points in a 2 mi² area in and directly adjacent to Perryville, revealed the groundwater system to be complex, with recharge areas being controlled by the locations of major cave systems and recharge amounts. Dye introduced at a given point may exit from three or more widely separated springs and resurgences. Dye tracing, potentiometric maps, spring discharge measurements, water quality data, and cave maps were used to define recharge areas for nine springs and karst resurgences. Major cave systems proved prominent in controlling directions of shallow groundwater movement. Rates of groundwater movement varied with precipitation, with rates exceeding 4 miles per day (mi/day) during peak recharge periods.

INTRODUCTION

Perry County is 70 mi southeast of St. Louis, Missouri, adjacent to the Mississippi River, on the eastern flank of the Ozark uplift (fig. 1). The western part of the county is underlain primarily by lower Ordovician sedimentary rocks. Extreme eastern Perry County is occupied by the Mississippi River flood plain, which varies from about 4 mi wide in Perry County, north of Perryville, to complete absence east of Perryville where the river follows the bluff line. Middle Ordovician and younger rocks form the bedrock surface in Perry County east of Interstate 55, which roughly follows the outcrop belt of the middle Ordovician St. Peter Sandstone.

The Perryville karst area, study area for this report, is bounded by the St. Peter Sandstone outcrop belt to the southwest, Blue Spring Branch to the northwest, Cinque Hommes Creek to the southeast, and the eastward limit of extensive sinkhole development to the northeast.

Much of Perry County east of Interstate 55 is intensely karstified. The surface contains thousands of sinkholes ranging from a few feet to nearly a mile in diameter and a few feet to over 100 ft deep. This sinkhole development is not confined to Perry County; from St. Louis to Cape Girardeau, large areas have

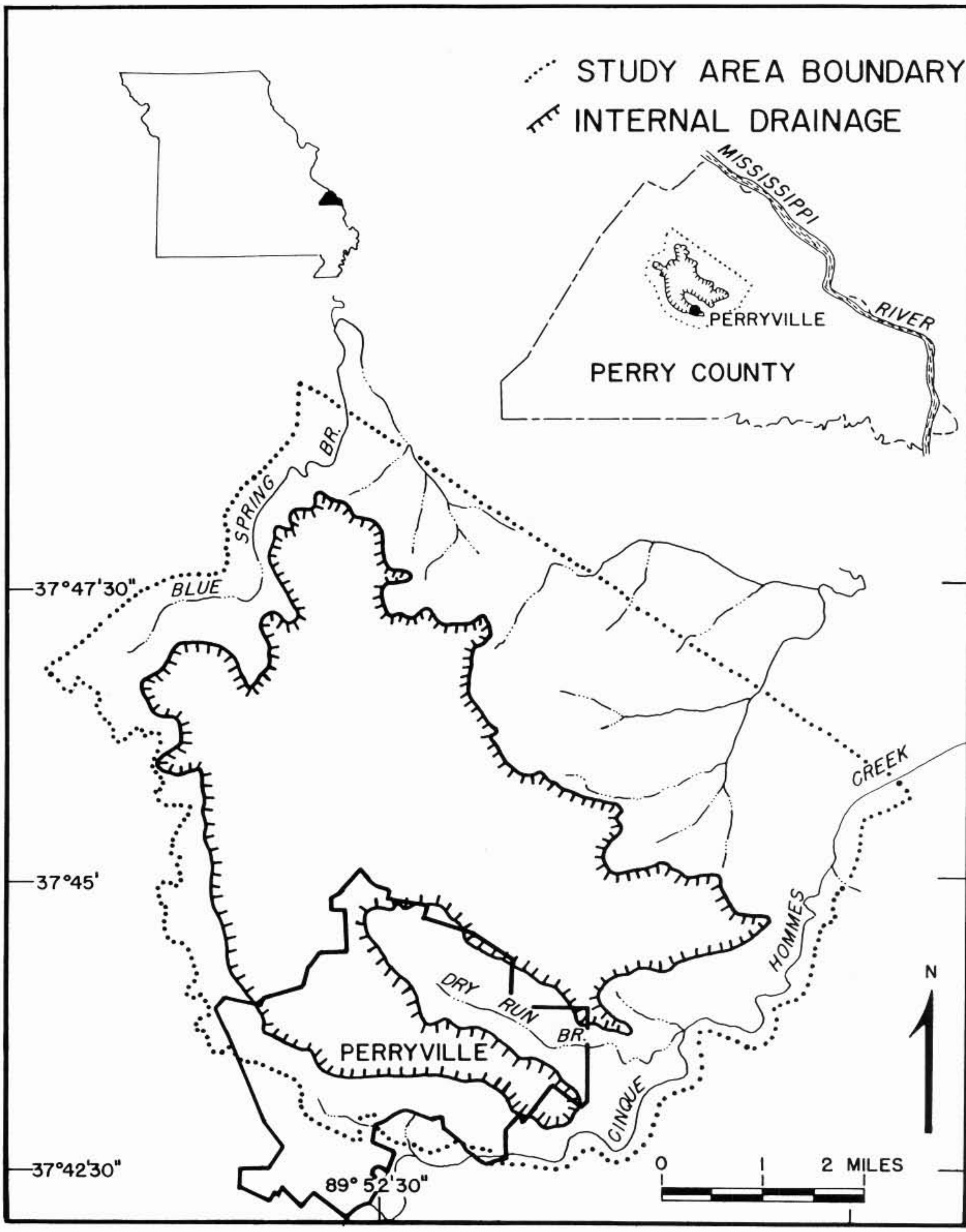


Figure 1 -- Location map of the Perryville karst area.

similar sinkhole development. These sinkhole plains, often several square miles in area, are internally drained through cave systems that recharge local springs and resurgences. Thus, any substance entering sinkholes in the karst areas can be expected to travel rapidly through the subsurface to a spring or karst resurgence.

The city of Perryville (population 7,343, 1980 census) once used the sinkholes in the city for disposal of sewage and stormwater runoff. Today, sewer lines have replaced sinkhole sewage drainage in most of the city, but the karst groundwater system is still relied on for stormwater drainage. Many sinkholes in Perryville have been modified to enhance stormwater drainage. Vertical inlet pipes have been placed in many to allow water to enter the underlying conduit systems more easily and to help lessen local sinkhole flooding. In two major areas, water from poorly drained areas is channelled to more open sinkholes. Despite these efforts, some areas of Perryville are still subject to local flooding after major precipitation. Several city construction projects are underway to improve drainage in areas that suffer from sinkhole flooding.

In 1956, when the Missouri Geological Survey (now the Department of Natural Resources, Division of Geology and Land Survey) published *CAVES OF MISSOURI*, author J Harlen Bretz, a well-known geomorphologist, described only four named caves in the county and had reports of a few unnamed caves. Today, 576 caves have been recorded in Perry County. They range from rock shelters only a few feet deep to complex systems many miles long. Four major caves in Perry County contain a total of more than 70 mi of mapped passage. With more than 27 mi of mapped passage, Crevice Cave, east of Perryville, is one of the 20 longest caves in the country.

The city of Perryville is on the southern edge of the Perryville sinkhole plain, an area containing more than 16 square miles (mi^2) of continuous internal drainage. No surface streams leave this 16-mi^2 area. In some areas of Missouri, caves are viewed as curiosities, but in Perry County they are critical segments of the drainage system, performing the function of surface streams elsewhere.

Previous Work

Perry County has not received extensive geologic or hydrologic attention. Fuller (1925) described, in general, the geology of the area, paying special attention to stratigraphy, structure, paleontology, and mineral resources. He also discussed the geomorphology, including the karst areas and the significance of the sinkholes and disappearing streams (Fuller, 1925, p. 16-19). Bretz (1956, p. 363-365) described four known caves in Perry County but observed, based on the extensive sinkhole areas, that "There is an unsolved problem in cave histories in Perry County." Vineyard and Feder (1974, p. 244-246) described the karst resurgences, or intermittent springs, along Blue Spring Branch and discussed the potential for other such springs, or resurgences, in the Perryville area. The view of Vineyard and Feder (1974, p. 246) was "There are doubtless many other resurgences similar to those described here, particularly in the karst areas near Perryville." Weaver and Johnson (1980, p. 119-120) present a brief history of caving in Perry County and describe a few of the larger caves. They also note the storm-runoff drainage problems in Perryville.

Beginning in the mid-1950s, organized cave study and exploration began gaining popularity among biologists, geologists (both students and professionals), and adventurers in general. "Spelunking" has evolved into a scientific discipline (speleology), and a number of organized caving groups have been formed across the Ozarks and elsewhere in the country. Cavers first revealed the true complexity of the Perry County karst. Crevice Cave, longest known cave in Perry County and Missouri, was first entered about 1960 and is now known to contain over 27 mi of mapped passage but still not fully mapped or explored. Cavers working in the Perryville area for the past 25 years are responsible for much available information concerning subsurface drainage patterns. Their work continues; new caves are discovered regularly and mapping continues in known caves.

ACKNOWLEDGMENTS

Though this report bears the name of only one author, the efforts of a number of people contributed greatly to the project's success. Don Meier, geologist, was employed by the Missouri Department of Natural Resources' Division of Geology and Land Survey through the first year of the study. He contributed greatly to early field work and the dye tracing program. Cynthia Endicott joined the project as a geological technician in September 1984, aiding in data compilation, field work, and final report preparation. The 1993 edition was revamped by Susan C. Dunn.

The efforts of Kent Bratton and the staff at the Southeast Missouri Regional Planning Commission are sincerely appreciated. Mr. Bratton could always be counted on to provide accurate observations on rainfall conditions, runoff, spring response times, and other data which contrubuted to the overall understanding of the groundwater system. Special thanks go to the city of Perryville for supporting the project with material and personnel assistance. Credit also goes to Gregory (Tex) Yokum, Mark Oliver, Jeff Rothgeb, Mark (Fish) Brooks, and the other cavers who have tirelessly worked the Perryville karst area for more than 20 years. Their contributions are greatly appreciated and it is hoped their fine work continues.

I am most appreciative of Bob Schumer, Building Inspector for the city of Perryville. Bob had the thankless task of collecting the hundreds of dye collection packets placed at springs. While working on this project, he came to understand the geology and shallow groundwater system of the area. Many of his thoughts and observations contributed to success of this project.

Special thanks go to the caving organizations and individuals who permitted the reproduction of their cave maps in this report. The map of Crevice Cave (1977) was drafted by Paul D. Hauck and surveyed by Paul D. Hauck, B.R. Knox, Osburn, Wilson, Matherne, Grither, Palmer, Emmendorfer, Seibert, House, and Baughn of Southeast Missouri State University Grotto, with the help of Little Egypt Student Grotto. Klump Cave (1973) was surveyed by Don Coons, Steve Bishop, Bob Heider, Dale Alyea, Alexia Cochrane, Judy Malkames, April Quehl, Dave Ryan, Gary Schaecher, and Joe Slivinski of the Little Egypt Student Grotto, with additions by E.L. Kern, Department of Earth Science, Southeast Missouri State University. The Map of Mertz Cave (1974) was drafted by Don Coons and surveyed by the Little Egypt Student Grotto. The map of Zahner Cave (1978) was drafted by Rick Frowein and surveyed by Jeanice Bleem, Steve Boehm, John Darin, Rick Frowein, Dave Letourneau, Mark Oliver, Loyd Spicer, Tom Zansius, and others of the Little Egypt Student Grotto. The map of the Moore Cave System (1980), Tex Yokum, Project Director, was drafted by Paul Hauck and surveyed by Lang Brod, Dr. Harry Walker, Lester Ambuehl, L. Spicer, J. Saberton, A. Clark, T. Hersch, D. Drum, R. Oesch, J. Yokum, T. Steinke, A. Steinke, S. House, and many others. Streiler City Cave (1984) was surveyed by Tex Yokum, Mark Oliver, Mark Brooks, Jeff Rothgeb, Sandy Trembley, Pam Saberton, Jerry Saberton, Alice Burgdorf, Jim Donnley, and Claire Betz; Tex Yokum was Project Director. Waters Street Cave (1984) was surveyed by Mark Oliver, Pam Burns, Jerry Saberton, Jeff Rothgeb, Mark Brooks, Alice Burgdorf, and Sandy Trembley; Tex Yokum was Project Director. The cave outlines shown in fig. 2 are from an overlay prepared by Tex Yokum.

Finally, I thank the residents of the Perryville area. In 22 months of field work, I failed to meet one person who was not friendly and appreciative of our work. I, in turn, appreciate their cooperation and understanding.

PURPOSE AND METHODOLOGY

The purpose of this study was to determine directions of movement of water entering the shallow groundwater system in and immediately adjacent to Perryville. Initially, little information existed concerning the discharge sites of the karst drainage systems, so extensive field work was required to determine locations of springs and karst resurgences. Beginning in January 1983, all surface streams bounding the karst area were examined. Specifically, Cinque Hommes Creek, upstream from sec. 2, T. 35 N., R. 11 E., to its confluence with Spring Branch, Spring Branch through its entire length, Dry Run Branch from Cinque Hommes Creek to its headwaters, Blue Spring Branch from Lithium to Brewer, and selected southern tributaries of Huber Branch. Along with the major drainages, each minor valley draining into it was investigated upstream to the upland areas. All springs and resurgences found were noted. No formal names existed for many of the springs, resurgences, and other karst features; for identification, these were named by the investigators. Local names may exist for some of these and we apologize for inadvertently renaming any of them.

Fluorescent dyes were used to trace water entering the ground, to springs or resurgences where the water reappeared. The dyes were injected at points of known karst groundwater recharge, such as sinkholes, swallow holes in stream channels, and cave streams, and later were collected using activated charcoal packets placed in springs, resurgences, and streams. Dye content was determined by using a spectrofluorometer.

Limited water quality and flow data were collected at major springs and resurgences to aid in defining the areas contributing water to each groundwater outflow point.

Physiography

Topography of the study area is gently rolling, with very few surface streams providing drainage. The few surface streams bound the sinkhole plain where drainage is through cave systems. Surface elevations vary from about 380 ft above mean sea level along lower Cinque Hommes Creek, to about 640 feet just northwest of Perryville. Relief is generally low except along the major surface drainages bounding the study area. A major portion of the study area, including most of the city of Perryville, is characterized by numerous shallow sinkholes and a few collapse sinkholes. The Perryville sinkhole plain, defined as the area of continuous sinkhole drainage in and adjacent to Perryville, covers more than 16 mi^2 and is underlain by several major cave systems, including the Moore Cave System, with more than 17 mi of passage; Crevice Cave with more than 27 mi of mapped passage; Mertz Cave, with about 1.8 mi of mapped passage; and Zahner Cave, with about 1.9 mi of mapped passage. Many other smaller caves are hydraulically connected to these major systems.

Figure 2 shows a single surface stream, Dry Run Branch, partially bisecting the Perryville karst area. The U.S. Geological Survey 7.5-minute topographic map of the area, which has a contour interval of 20 ft, shows Dry Run Branch as a normal surface stream. However, field work has shown the stream to be more intimately associated with subsurface than surface drainage.

The Perryville sinkhole plain is principally developed in the Joachim Dolomite but also includes an area underlain by the Plattin Formation. Most cave development is in the Joachim. At one time, at least, the area of continuous sinkhole development probably extended northeast beyond the present boundaries of the karst area. Many isolated sinkhole areas are found between the major karst area and the Mississippi River. Headward erosion of surface streams, such as Huber Branch, McClannahan Branch, Streile Branch, and other drainages east and north of the sinkhole plain, have possibly obliterated the older karst surface. Many more shallow sinkholes are in the area than are shown on the topographic maps with 20-ft contour intervals.

Sinkhole plain development in the Perryville karst extends northwest and southeast along the Mississippi River, from St. Louis to Cape Girardeau. The sinkhole areas are generally breached every few miles by major easterly flowing surface streams.

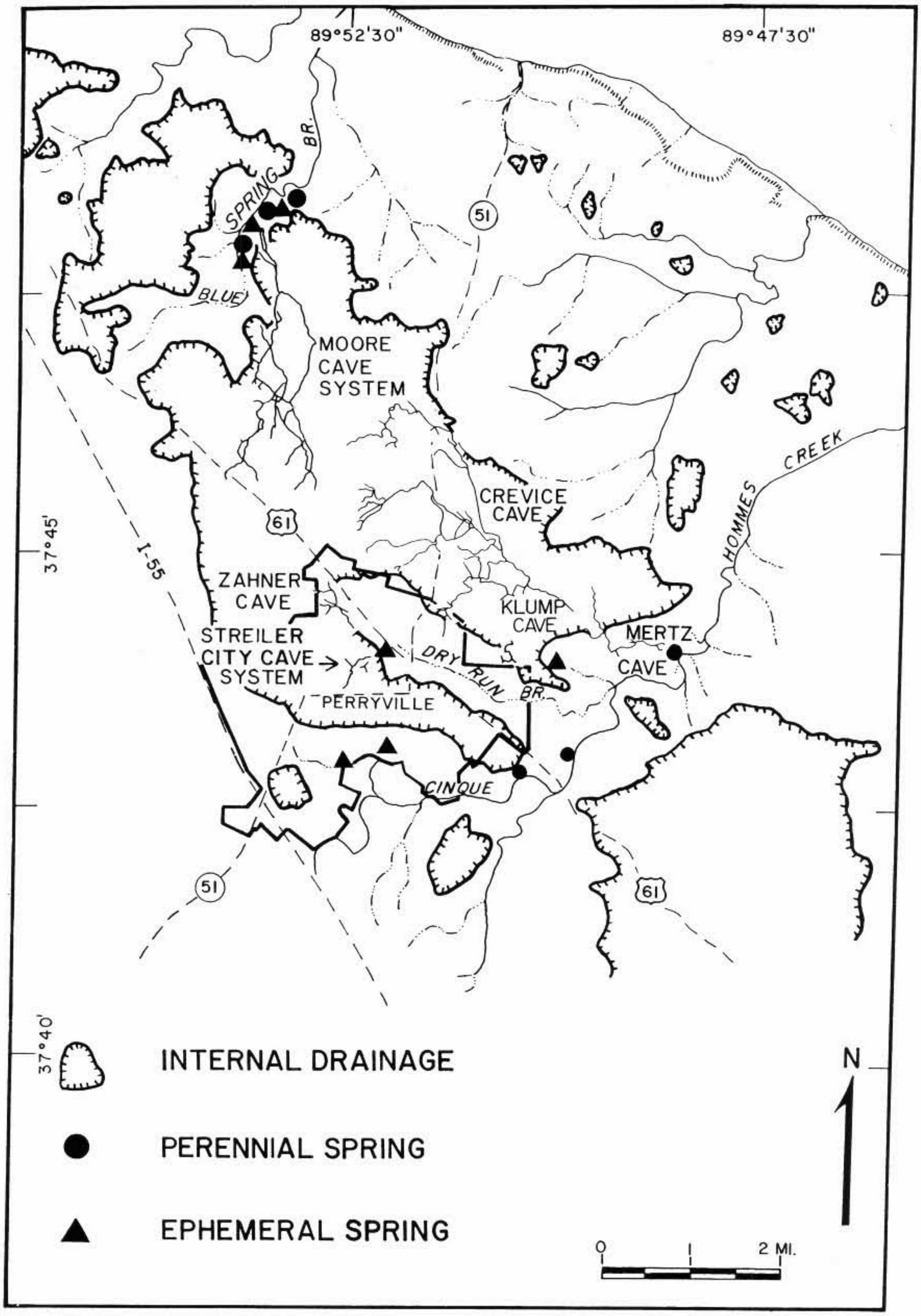


Figure 2 -- Physiographic features of the Perryville karst area.

Geology of the Study Area

The study area is on the east flank of the Ozark uplift and is underlain by middle Ordovician or older rocks. The basal rock unit exposed in the area is the St. Peter Sandstone, a fine- to medium-grained quartzose sandstone, about 60 to 200 ft thick, which crops out along the southwestern part of the study area and is well exposed in the southern part of Perryville. Where exposed, the St. Peter is generally brown with a case-hardened surface. This sandstone unit essentially forms the base of karst development in the study area.

The Joachim Dolomite unconformably overlies the St. Peter and forms the bedrock surface throughout the central part of the study area. It is best exposed along valley walls of most of the area streams. The unit is a yellow-brown silty dolomite containing limestone interbeds and minor shale; it has relatively little chert, and some sand beds near its base. A stratigraphic unit no longer formally recognized in the study area by the Division of Geology and Land Survey is the Rock Levee Formation, originally defined as including the upper part of the Joachim and the lower part of the Plattin Formation. The boundaries were based on insoluble residues, not lithology. The Rock Levee is now formally included in the Joachim dolomite, which is about 250 ft thick in the study area.

The Plattin Formation forms the bedrock surface throughout the northeastern part of the study area. The unit is gray to dark-gray, finely crystalline to sublithographic limestone with minor shale beds; the limestone generally exhibits conchoidal fracture. The Plattin reaches a maximum thickness of about 350 ft in the area. Both the Joachim Dolomite and Plattin Formation thicken to the southeast.

Though the Plattin is the youngest unit exposed in the study area, a few miles east of the study area extensive faulting has brought Mississippian rocks to the surface, where they abut middle Ordovician rocks. Figure 3 is a geologic map of the study area.

The upland surfaces have a significant cover of up to about 30 ft of Pleistocene loess, originally a wind-blown silt, primarily derived from the Mississippi River flood plain. Loess is easily eroded from tilled farmland and contributes greatly to the sediment load of area streams and springs. Springs and resurgences, after heavy rain, flow muddy due to excessive suspended sediments.

The study area is on the eastern flank of the Ozark uplift. The bedrock generally dips northeast at about 100 ft/mi or slightly less. The bedrock surface is somewhat undulating, so dip is not constant. Structural relief across the study area is about 600 ft. Structure contour maps drawn on two datums, the base of the Plattin Formation and the base of the Joachim Dolomite, show no major geologic structures in the study area (figs. 3 and 4). The map drawn on the base of the Joachim, however, does show a north-trending, north-plunging, mildly asymmetric anticline between Highway 51 and Blue Spring Branch. This structure is between the Moore Cave system and Crevice Cave and may partly control groundwater movement in the area of the anticline. The map drawn on the base of the Plattin Formation, however, does not show the structure extending into the Plattin.

Just northeast of the study area, along the bluffs of the Mississippi River, are a series of northwest-trending faults with up to several hundred feet of vertical displacement. This segment of the Ste. Genevieve fault system is the major structural feature of the area but does not directly bear on groundwater movement in the study area. Other minor folds and faults probably exist in the study area, but subsurface data-control points are too sparse to identify them.

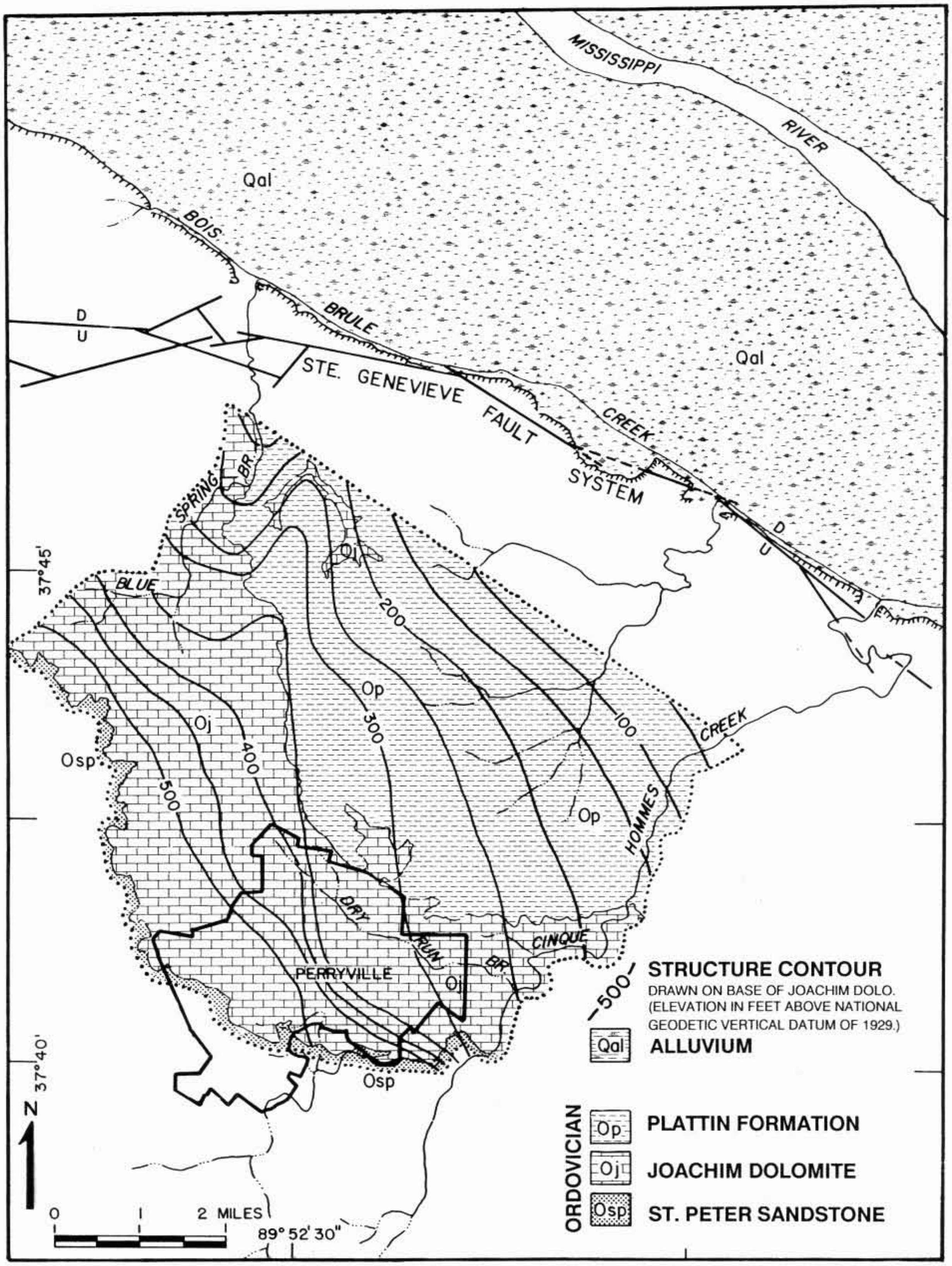


Figure 3 -- Geologic and structure contour map drawn on the base of the Joachim Dolomite.

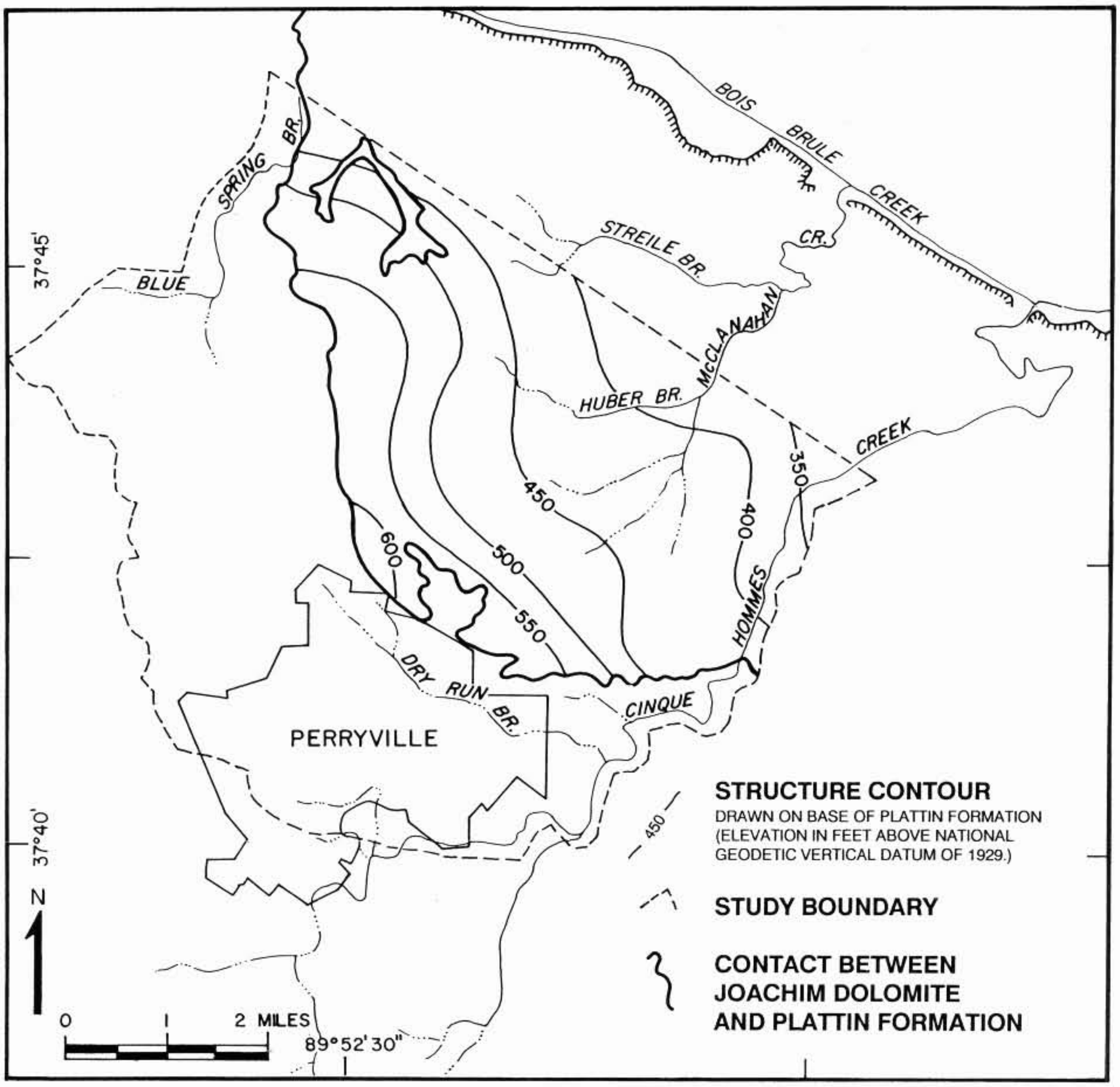


Figure 4 -- Structure contour map drawn on the base of the Plattin Formation.

DESCRIPTION OF KARST FEATURES

No area in Missouri contains more extensive karst development than the Perryville karst area. Within it are a number of specific karst features that must be understood to picture clearly the function of the karst drainage system. It is unnecessary to describe each sinkhole and cave, but a general understanding of sinkholes and caves is needed to appreciate their role in the karst drainage system. The sinkholes are most significant when considered collectively. Some caves are paramount in subsurface drainage, but others are not current groundwater flow routes.

Locations of the karst features discussed are given by longitude and latitude. A portion of the area was originally divided by Spanish land grants and cannot be accurately identified by section, township, and range. Figure 5 shows locations of the karst features discussed. Unless noted, those described are privately owned; permission should be obtained from owners before attempting to visit them. All of the caves in the Perryville karst are privately owned. Visiting them without permission is trespassing, and jeopardizes landowner-caver relationships. Those wishing to visit the caves are encouraged to contact the Missouri Speleological Survey c/o the Missouri Department of Natural Resources' Division of Geology and Land Survey, P.O. Box 250, Rolla, MO 65401.

Some definition, or at least explanation, of terms used to describe karst features are necessary. The terms *spring* and *resurgence* are commonly used synonymously in karst areas. Generally, *spring* implies a natural opening from which groundwater flows from the subsurface. Springs normally have a sustained base flow. Though spring flows decrease during dry weather, most springs do not cease to flow except, perhaps, during extreme droughts. The term *resurgence* is used several ways. Most correctly, it is the rising of an underground stream. In Europe, it is reserved for the emergence of a cave stream that earlier sank upstream (Monroe, 1970, p. K-14). In the study area, the term is used for springs which are characteristically intermittent; they function only after precipitation, and during dry weather, cease flowing. Few springs in the study area discharge water during very dry weather.

Caves are well-known features, and few people have not at some time entered one. Commercial or show caves are common in Missouri and many other states. In brief, most caves are formed by dissolution of soluble rock. Slightly acidic groundwater, provided by rainfall that has combined with carbon dioxide to form a weak carbonic acid solution, and becoming even more acidic by mixing with carbon dioxide and acids in the soil, moves through and dissolves the soluble bedrock, each drop removing a minute amount of rock. This initial solution occurs below the water table, where the rock is saturated. Later in the cave's history, after the subsurface drainage system has been established and the position of the water table lowered by base level lowering, water flowing through the cave system en route to springs and resurgences will further erode the bedrock passages, altering the original shape of the wall rock.

Two major cave systems drain the Perryville karst area. These are both complex systems with numerous passages, some providing avenues for groundwater, others being dry. Dry passages may be former water passages that, due to deepening of the cave systems, no longer channel groundwater to springs and resurgences.

Sinkholes, topographic depressions formed by subsurface removal of soil and rock, are the primary collectors of water entering the karst groundwater system in the Perryville karst area. In the study area they are characteristically broad, shallow depressions, several times wider than deep, and of low vertical relief. Some contain a ponor, or open throat, leading into a cave or solution-enlarged openings providing drainage. Collapse sinkholes, often as deep as wide, or deeper, with vertical or subvertical sides are more rare. The two types of sinks vary not only in appearance, but often develop differently. All sinks do not form catastrophically by collapse. They may originate by upward stoping as soil materials are removed by water moving through smaller cave passages or solution enlarged fractures. The initial sinkhole develops when the soil roof can no longer support its own weight and subsides, thereby leaving a vertical or bell-shaped pit developed mostly or entirely in soil materials. Subsequent erosion of side materials soon forms the cone-shaped sinkhole. A collapse sink, on the other hand, may be caused by collapse of a cave ceiling in a large room or at the intersection of several cave passages, leaving a sink that contains bedrock as a portion of the walls. In either case, the resulting depression is a natural trap for water falling in its boundaries.

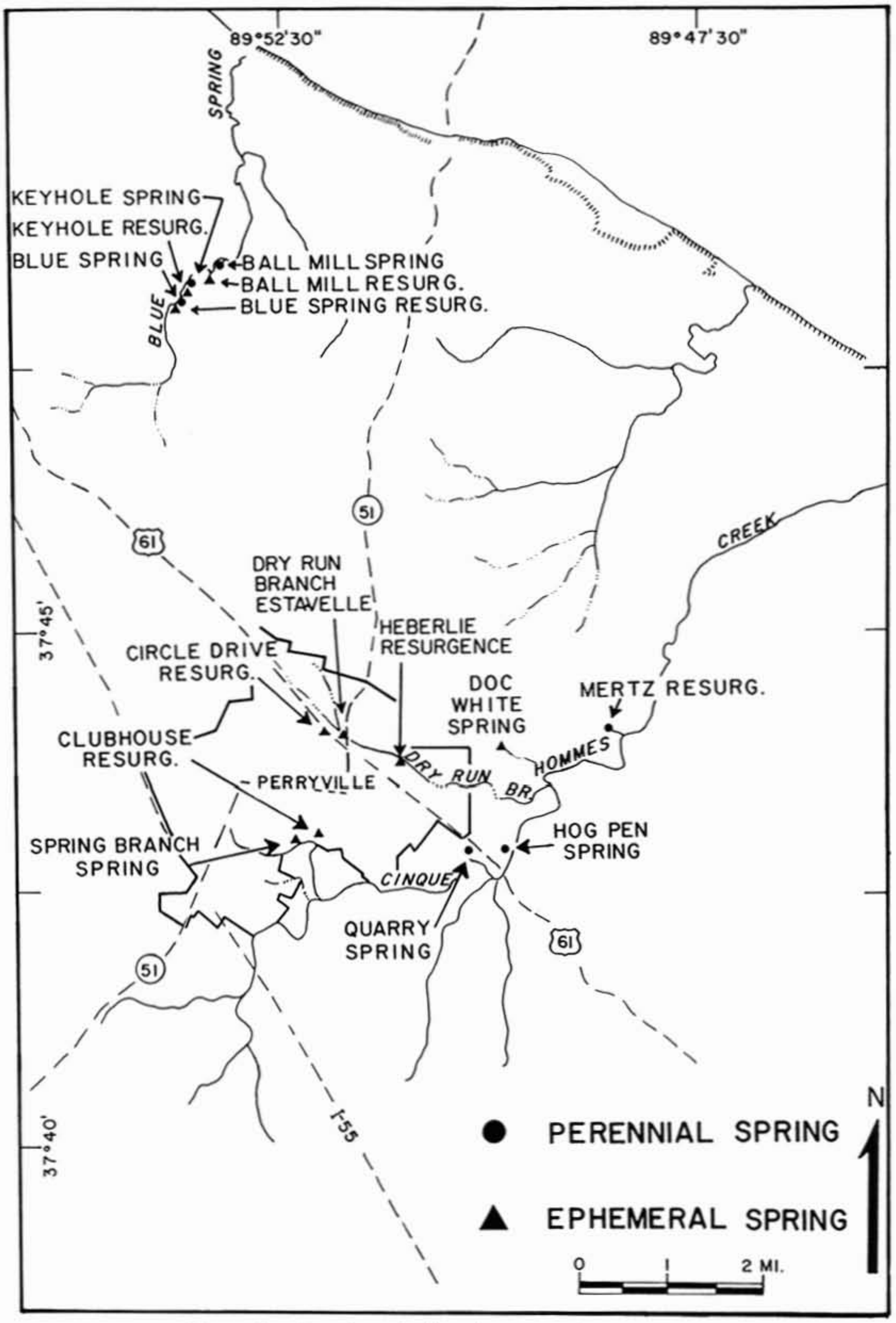


Figure 5 -- Locations of selected springs and resurgences.

Much of the Perryville sinkhole plain consists of uvalas, large depressions containing a number of smaller individual sinkholes. Only a few of these are obvious on 7.5-minute topographic maps of the area, but on the more detailed 1:2400-scale topographic maps of Perryville, drawn on 4-ft contour intervals, many valley sinks, or linear arrangements of sinkholes, are present.

Losing streams are another type of recharge feature of karst terrain. Basically, a losing stream is one which channels a significant amount of its flow from the surface into the subsurface. The water loss may occur at a single point or over a longer reach of the stream. The zone of water loss may be obvious, a swallow hole or swallet developed in bedrock, or a sinkhole in the stream channel, or it may be well disguised, such as solution-enlarged fractures beneath a gravel streambed. In either case, the features serve as recharge mechanisms for groundwater.

KARST FEATURES ALONG CINQUE HOMMES CREEK

A number of springs and resurgences are developed along or drain into Cinque Hommes Creek, but only the features on the northern side of the creek are discussed in this report. On the south side are a number of resurgences that discharge large amounts of water during wet weather, but these are associated with cave systems and surface karst south of the study area.

Mertz Resurgence (37°44'06" N, 89°48'36" W)

Mertz Resurgence, also known as Sutterer Spring, is the most conspicuous groundwater discharge point along Cinque Hommes Creek (fig. 6). The water emerges from a cave opening at the base of a bluff 100 ft high. The spring and bluff are developed in Joachim Formation; the Plattin Formation is exposed at the top of the hill overlooking the spring. The emerging water has carved a channel some 20 ft wide and nearly 9 ft deep in fine-grained flood plain sediments. The cave behind the spring can be entered for about 100 ft where the stream siphons and the passage is completely water filled. Drainage from Mertz Cave and Crevice Cave exit from the spring.

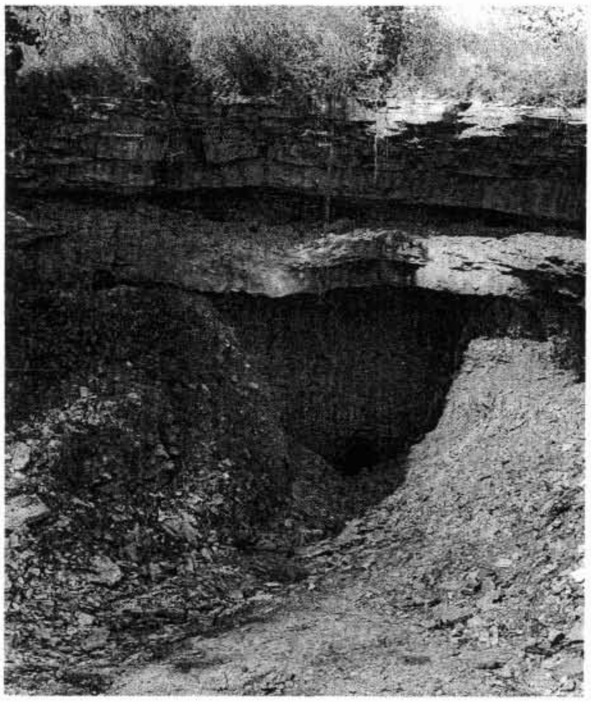
Doc White Spring (37°43'54" N, 89°49'52" W)

Doc White Spring is upstream from Mertz Resurgence, in the upper watershed of an unnamed tributary of Cinque Hommes Creek. The spring has not been mentioned in published reports. The water rises from the base of a low bluff of Joachim Dolomite, from what apparently was once a cave passage. Breakdown and other debris have choked the entrance, allowing water to escape but foiling attempts at human entry. Contrary to its name, Doc White Spring is not perennial; flow ceases during extended periods of dry weather (fig. 7). More fascinating than the spring itself is the geomorphology of the immediate setting. The area near the spring and a part of the spring branch appear to be collapsed cave. A bedrock pillar, some hundred feet in diameter, 10 ft high, and only a few feet from the spring, is interpreted as a remnant of cave wall between intersecting cave passages (fig. 8). At the base of the pillar, on the spring side, is a small, vertical-sided sinkhole about 4 ft in diameter and depth. Even after the spring stops flowing in dry weather, water continues to flow through the bedding-plane opening at the base of the sink, a circumstance indicating that the spring opening may be an upper level outlet for a cave stream, not the ultimate discharge point of a karst drainage system. In September 1984, during dry weather, a backhoe was used to remove debris blocking the spring opening. It was discovered that the spring rises through an opening at the end of an oblong room about 20 ft long and 8 ft wide. Along one side of the room, water is about 5 ft deep but along the opposite side, it is much deeper and presumably rises along that wall.

Hog Pen Spring (37°42'56" N, 89°49'49" W)

Hog Pen Spring is developed in Joachim Dolomite, in a hillside along the northwest side of Cinque Hommes Creek, about 1200 ft downstream of the Highway 61 bridge. The spring consists of multiple bedding-plane openings, all too small for human entry (fig. 9). During dry weather, only the lower two openings discharge water, but after major

Figure 6 -- Mertz Resurgence during low-flow conditions.



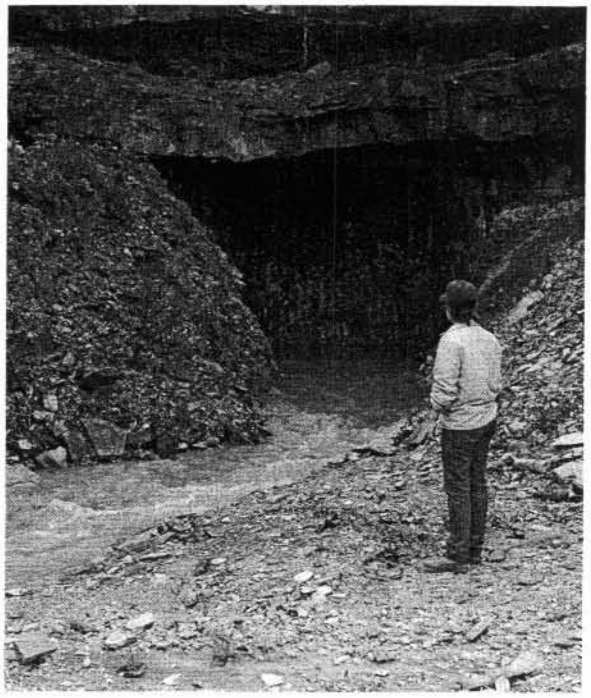


Figure 7 -- Doc White Spring after debris blocking the entrance was removed (7A). The spring begins discharging within a few hours after moderate or heavy rainfall (7B).

storms, large volumes of water discharge from several openings about 20 ft above and a short distance northeast of the low flow openings.

Quarry Spring (37°42'56" N, 89°50'16" W)

Quarry Spring rises in a small tributary of Cinque Hommes Creek, just east of the county quarry, which is in Joachim Dolomite. Spring flow is generally small, but the meager base flow is well sustained.

Clubhouse Resurgence (37°43'07" N, 89°52'06" W)

This resurgence, in a small valley draining only a few acres on the south side of Perryville, was discovered during the dye-tracing program when dye from a trace was detected in Spring Branch downstream of the valley but not upstream. The resurgence, developed at the St.Peter Sandstone-Joachim Dolomite contact, has a low, but well-sustained, base flow but after heavy rainfall, discharage increases greatly. Water flows from several solution-enlarged bedding-plane openings in the side of the hill and valley floor. The sporadic discharge characteristics indicate a limited recharge area.

Spring Branch Spring (37°42'59" N, 89°52'19" W)

Spring Branch Spring flows from a bedding-plane opening adjacent to the channel of Spring Branch, about 700 ft upstream from the Kiefner Street bridge. The spring is small compared to others in the study area and is difficult to measure, due to its proximity to the creek. Observations during this study indicate that the spring normally has very low discharge and stops flowing during periods of low rainfall; it probably has a very small recharge area.

Figure 8 -- View toward the northeast, of Doc White Spring. The spring flows from the low bluff on the left. The cave-passage collapse exposing the spring left the bedrock pillar (right-center) and pirated a small surface stream. The original stream channel follows the field road (center).

KARST FEATURES ALONG DRY RUN BRANCH

A number of karst features along Dry Run Branch are directly related to shallow groundwater recharge and discharge. Dry Run Branch is the only surface stream which extends any significant distance into the Perryville sinkhole plain; it is bounded by uplands marked with sinkholes. Though topographic maps show no sinkholes along the creek, numerous sinks are developed in the flood plain upstream from Highway 51 and in a few places downstream from Route E. A number of sinkholes and losing stream segments occur along Dry Run Branch

Heberlie Resurgence (37°43'46" N, 89°51'04" W)

Heberlie Resurgence is an intermittent spring in a subdivision near the end of St. Augustine Street, in the eastern part of Perryville. The resurgence can no longer be seen; a vertical rise pipe equipped with an inclined corrugated steel tube drains water from the resurgence to Dry Run Branch, about 200 ft away (fig 10). Observations during this study, by Bob Schumer, Building Inspector, city of Perryville, and Kent Bratton, Southeast Missouri Regional Planning Commission, indicate that the resurgence begins functioning about an hour after moderately heavy precipitation. The resurgence has been viewed discharging about 30 gallons per minute (gpm) after a 2-hour rainstorm but higher flows probably occur after extremely heavy precipitation. The resurgence stops discharging within about a day after precipitation ends.

Circle Drive Resurgence (37°44'04" N, 89°51'58" W)

Circle Drive Resurgence, more accurately termed an estavelle, or reversible sinkhole, is between Highway 61 and Circle Drive in the north part

Figure 9 -- Hog Pen Spring after heavy rainfall.

of Perryville. During dry weather, the resurgence appears simply to be a cave entrance some 3 ft high and 8 ft wide developed in Joachim Dolomite. After lesser rainfall events, surface water draining into the resurgence channel from the area around it flows into the cave. During periods of heavy rainfall, the flow reverses and large amounts of water are channeled out of the cave for brief periods, generally only a day or two, before the cave ceases functioning as a spring (fig. 11).

Dry Run Branch Estavelle (37°44'02" N, 89°51'47" W)

This feature, about 200 ft upstream from Highway 51, is a sinkhole developed in the channel of Dry Run Branch. The sink is not well defined, because alluvial gravel fills it. It functions somewhat differently than a sinkhole. Much of the time, the hole intercepts the flow of Dry Run Branch and channels it into the subsurface. The amount of water the feature is capable of handling before water flows past is not known, but flows exceeding 100 gpm have been observed disappearing into the subsurface. After very heavy rainfall, however, the estavelle discharges water. In September 1984, when the estavelle was first observed discharging water, several cubic feet of water per second were rising from the bottom of the creek and from holes along the banks. Streambanks up- and downstream from the sinkhole in the channel have been altered by recent sinkhole collapses.

Dry Run Branch downstream of Highway E flows directly on bedrock much of its course. There are several places where flow ends in shallow, gravel-floored pools. Downstream from the losing zones the creek is dry until more flow is added from small springs adjacent to the creek. This cycle is repeated several times before Dry Run Branch intersects Cinque Hommes Creek.

Figure 10 -- Herberlie Resurgence discharges through an inclined tube linked to a vertical rise pipe (upper center).

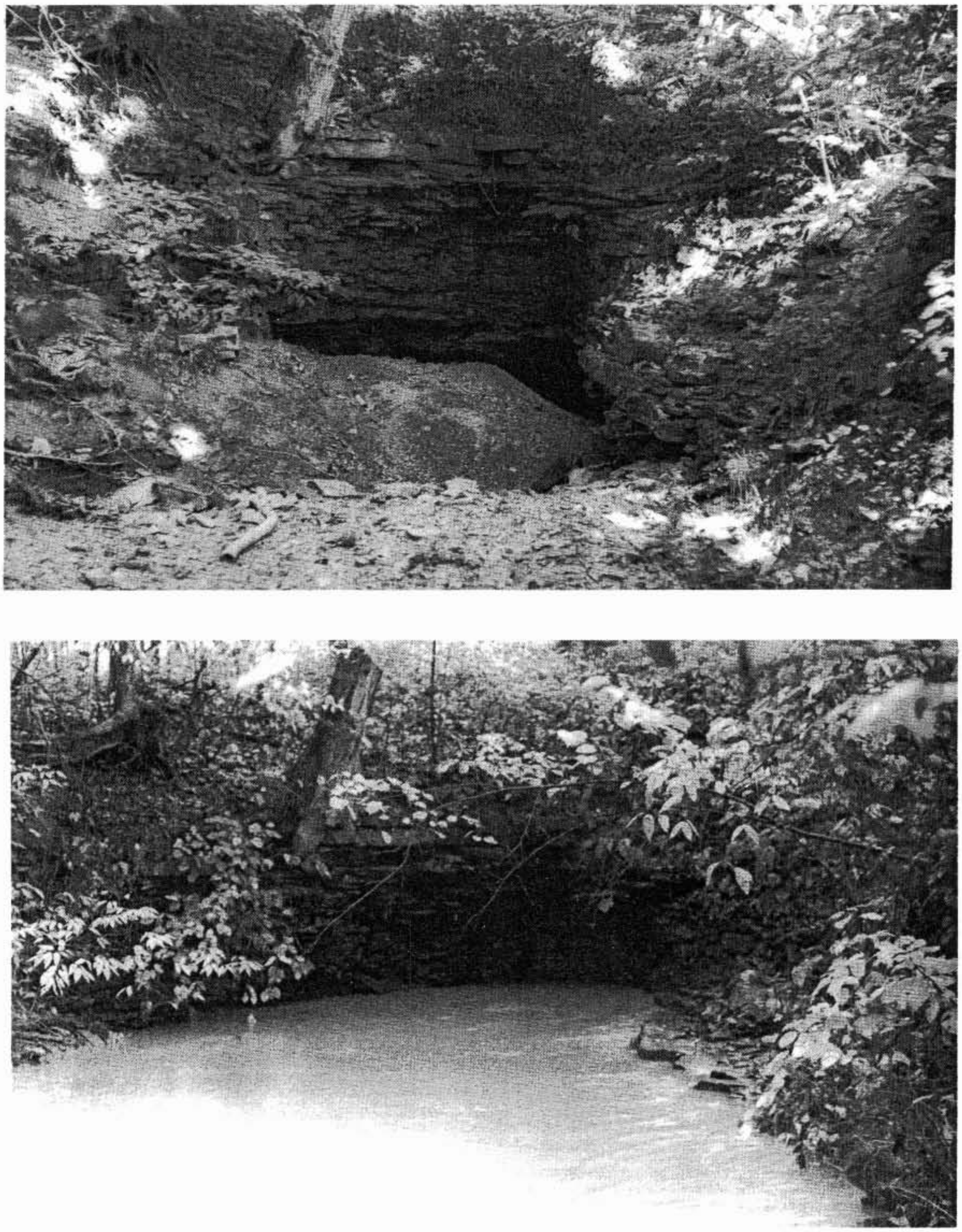


Figure 11 -- Circle Drive Resurgence is normally dry (11A). After light precipitation, water flows into the cave. After heavy rainfall (11B), the resurgence discharges large quantities of stormwater runoff from the northwestern part of Perryville.

KARST FEATURES ALONG BLUE SPRING BRANCH

Blue Spring Branch forms the western boundary of the study area and developed along its eastern bluff line are a series of unique karst features that were first described by Vineyard and Feder (1974, p. 244-246). Downstream from Perry County Road 914 are several perennial springs and intermittent resurgences. The springs have relatively well-sustained base flows, though in dry weather they diminish greatly. The resurgences are physically different from the springs and serve as overflow outlets for the karst groundwater system.

Blue Spring and Blue Spring Resurgence (37°48'09" N, 89°53'42" W)

These two features are less than 500 ft downstream from Perry County Road 914 on the east side of Blue Spring Branch. Blue Spring is developed in Joachim Dolomite at the base of a short bluff. Water flows from a solution-enlarged bedding plane opening partly filled with breakdown rubble. Gregory J. Yokum (1980, written comm.) has shown Blue Spring to be the rising of the cave stream of the Moore Cave System (fig. 12). Blue Spring Resurgence, immediately upstream of Blue Spring, is a high-water overflow outlet of the Moore Cave System. When the discharge capacity of lower Berome Moore Cave, or Blue Spring, is exceeded by recharge, Blue Spring Resurgence begins functioning. In flood stage, water issues from the 20-ft-diameter 5-ft-deep rise pit and flows past Blue Spring to nearby Blue Spring Branch. Blue Spring Resurgence, like all karst resurgences along Blue Spring Branch, functions only briefly after heavy precipitation, until the excess water is channeled out of the cave system and Blue Spring can again accommodate the flow. Four hundred feet downstream of Blue Spring is another resurgence, Keyhole Resurgence, a karst water discharge point that is also a high-flow outlet of the karst drainage system.

Six hundred feet further downstream, Keyhole Spring rises from a small circular basin in the flood plain of Blue Spring Branch. Water rising from the sand-bottomed pool flows down a narrow spring branch to Blue Spring Branch. The hydrologic significance of Keyhole Spring and Keyhole Resurgence has not been determined by dye tracing. Keyhole Resurgence may be related to drainage of the Moore Cave System, but it seems unlikely that Keyhole Spring is. One or both features probably receive recharge from the sinkhole plain east of the Moore Cave System.

Ball Mill Resurgence and Ball Mill Spring (37°48'48" N, 89°53'21" W)

Certainly the most striking karst resurgence associated with the Perryville karst area is Ball Mill Resurgence. The feature lies at the base of a 40-ft bluff of Joachim Dolomite, several hundred feet south of Blue Spring Branch (fig. 13). The rise basin, some 20 ft in diameter and 8 ft deep, is empty of water, except after very heavy precipitation, and is floored with well-rounded cobbles, the product of the natural milling of rocks striking each other when flood water rushes upward through the cobbles flooring the basin. Fresh rock falling from the bluff above the spring keeps the mill supplied with abrasives and raw materials. The very brief functioning of the resurgence after heavy precipitation indicates that its recharge area is fairly small but very open and interconnected. This feature is owned by the L.A.D. Foundation and managed by the Missouri Department of Conservation. Ball Mill Spring, a small spring a few hundred feet north of Ball Mill Resurgence, may discharge the base flow of the karst drainage system supplying Ball Mill Resurgence.

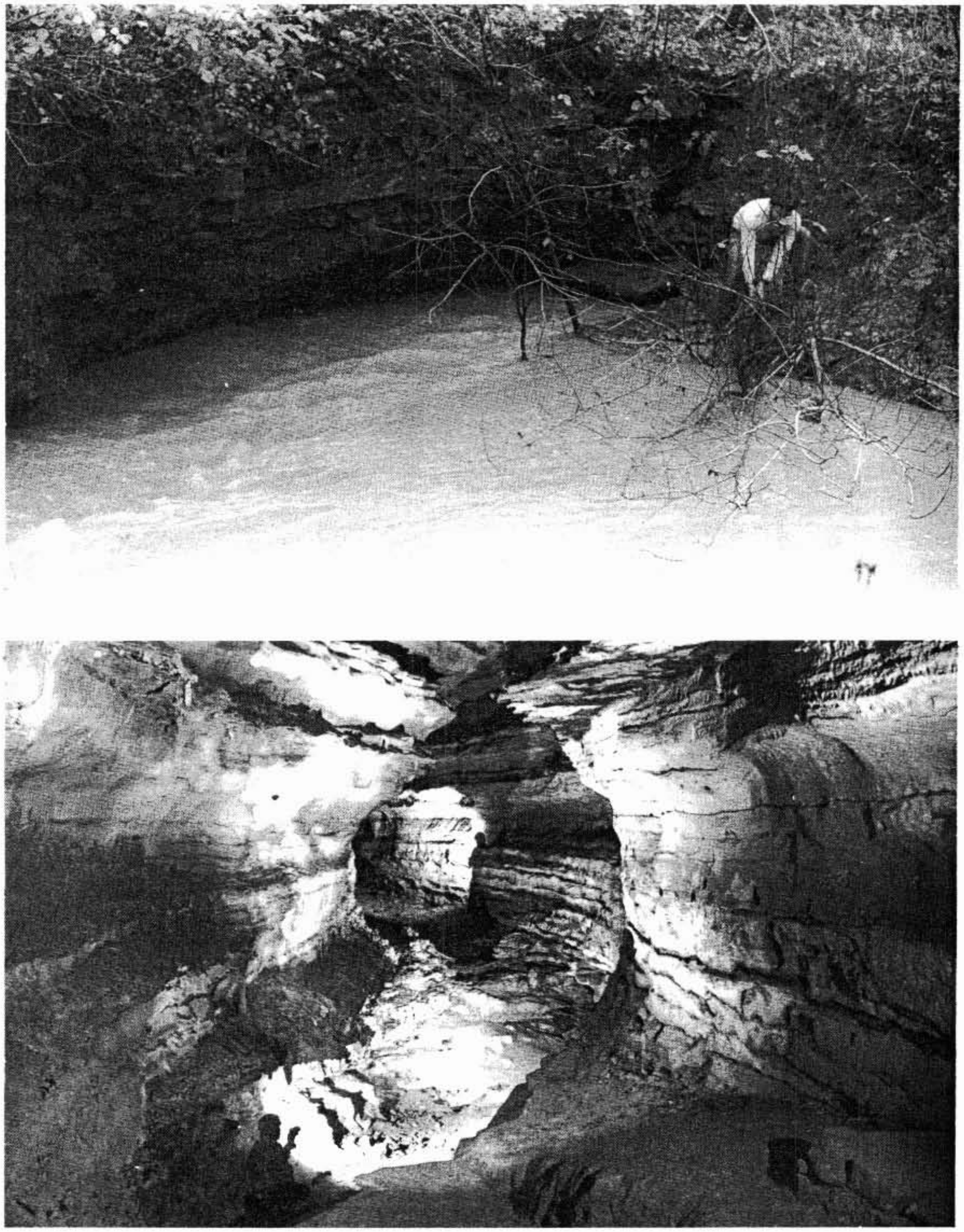


Figure 12 -- Blue Spring (12A), shown after heavy rainfall, is the largest perennial spring along Blue Spring Branch. The Moore Cave System (12B) is part of the conduit system that transports water to the spring.

Figure 13 -- View of Ball Mill Resurgence from the top of the 50-ft bluff behind the curcular rise pool.

DYE TRACING PROGRAM

For more than 20 years, fluorescent dyes have been used to trace movement of underground waters. The dyes, which are environmentally safe in the concentrations used for groundwater tracing and are detectable in very low concentrations, are placed where water enters the subsurface, such as sinkholes, losing streams, swallow holes, and in cave streams. Springs, resurgences, and gaining streams are then monitored for the presence of dye.

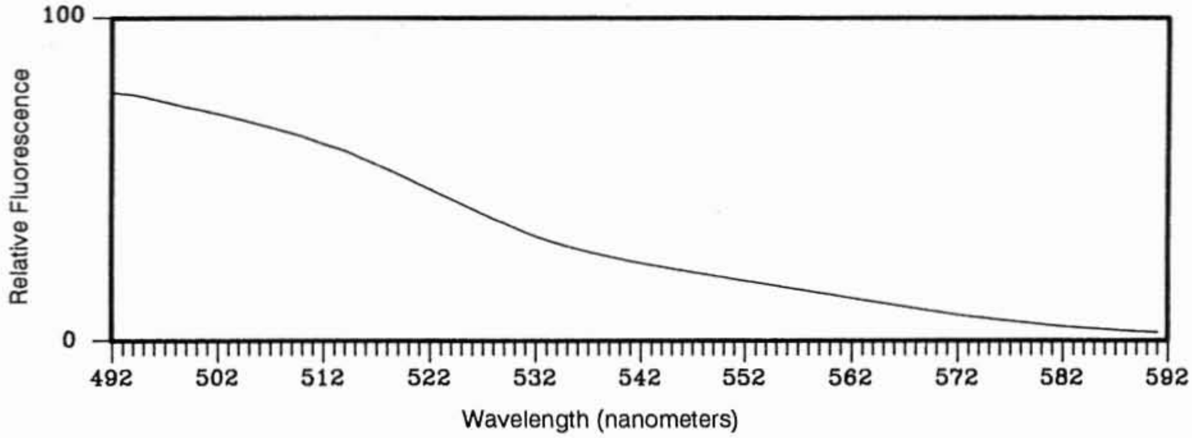
Two fluorescent dyes were used in this study. Fluorescein, a yellow-green fluorescent dye available from a number of sources, under the color-index generic name of Acid Yellow 73, is detectable to about 0.5 micrograms per liter (µg/l) under laboratory conditions. The second dye used was Rhodamine WT 20% (Acid Red 388), is a red dye with laboratory detection limits similar to fluorescein.

Fluorescence is the property that renders these dyes especially useful for groundwater tracing. Ultraviolet light directed on a fluorescent dye excites some of its electrons to a higher energy state. As the electrons return to ground state, photons of light are emitted. The emitted energy usually has a longer wavelength than that absorbed. A fluorometer is an instrument used to detect and quantify fluorescent materials. In this study a Farand model Mark I scanning spectrofluorometer was used for dye detection. Before dye was injected into the groundwater system, dye recovery packets containing activated coconut charcoal were placed in locations where the dye could emerge. The packets were collected and, in the laboratory, were washed and elutriated with a 5% solution of ammonium hydroxide in ethyl alcohol. Dye adsorbed on the charcoal is released by the change in pH value. After elutriating for 1 hour, 4 milliliters (ml) of elutriant were drawn off and placed in quartz cuvettes (sample holders).

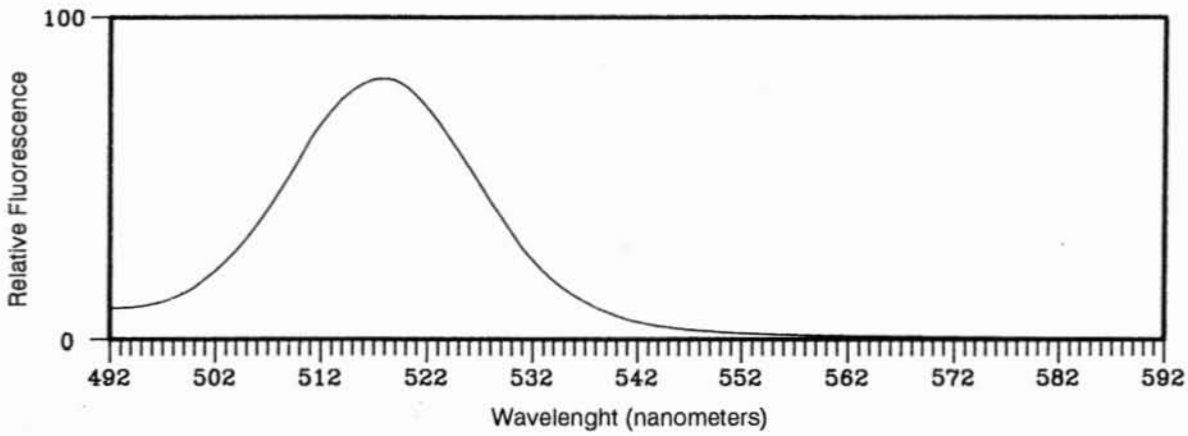
The scanning spectrofluorometer is very useful in detection of dye because the excitation and emission wavelengths can be selected independently. The excitation and emission peaks of the dyes used were determined experimentally. Fluorescein was found to have an excitation peak of 500 nanometers (nm) and an emission peak of 517 nm, a 17-nm spacing. Rhodamine WT has an excitation peak of about 550 nm and an emission peak of 568 nm, an 18-nm spacing. To analyze for dye content, the monochromators on the spectrofluorometer were adjusted for a spacing of 17 nm, with the excitation wavelength the lowest of the two. Samples were scanned from about 30 nm below the fluorescein excitation peak to about 30 nm above the emission peak of Rhodamine WT. Dimensionless fluorescence values were recorded on a chart recorder. Figure 14 shows typical synchronous-scan graphs of samples containing fluorescein and Rhodamine WT dyes. Background-sample graphs are also shown. The spectrofluorometer allowed two dyes to be used simultaneously, enhanced dye detection, and aided in eliminating confusion due to the presence of extraneous fluorescent substances.

A hindrance in all dye tracing studies is the presence of extraneous fluorescent materials. Fluorescein dye has several uses other than dye tracing. The dye is commonly used in automobile antifreezes and also in certain toilet bowl cleaners. Groundwater contamination from antifreeze solutions is probably not a problem but the toilet bowl cleaners containing fluorescein can cause problems, especially if the product is used in a rural karst setting where a central sewage collection system is not used. Before starting the dye-tracing program, dye-collection packets were placed in springs and resurgences to obtain background fluorescence data. Several springs and resurgences were found to contain fluorescent materials with spectral characteristics identical to fluorescein. This posed a serious problem only with Hog Pen Spring, which routinely yielded samples having high fluorescence values in the fluorescein range, before any fluorescein dye was used. Thus, when dye traces were run from areas that had a good potential for recharging Hog Pen Spring, either Rhodamine WT was used, or enough fluorescein to compensate for the high background values. Fluorometric values for a positive dye trace were generally in the range of 1000 to 10,000 units. The high background values of Hog Pen Spring generally were under 100 units.

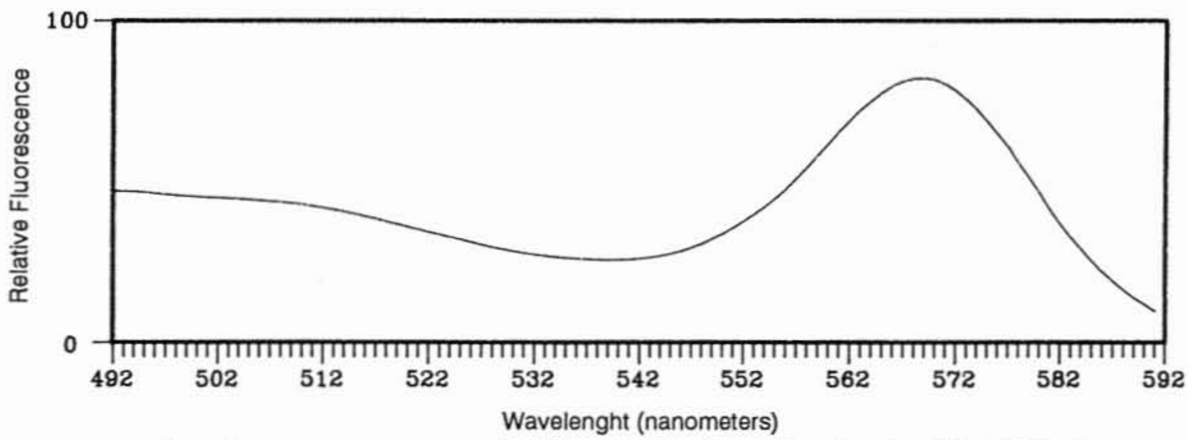
In initiating a dye trace, a water source should be present to carry the dye into the subsurface. If the dye could not be placed in moving water, water was hauled to the injection site in the city's hydraulic sewer-rodding truck and pumped in with the dye, or a nearby fire hydrant was opened. Usually, 1000 gallons or more of water were added at dry-dye injection sites. The amounts of dye used varied. The first few dye traces were run using either 3 lbs of fluorescein or 3 liters of Rhodamine WT 20% dye. Trial and error revealed that traces could be success-



Synchronous scan graph, 17 nm. spacing, no fluorescent material present.



Synchronous scan graph, 17 nm. spacing, fluorescein dye.



Synchronous scan graph, 17 nm. spacing, Rhodamine WT 20% dye.

Figure 14 -- Spectrofluorograms showing characteristic background, fluorescein, and Rhodamine WT plots.

fully run using ½ to 1 lb of fluorescein or ½ to 1 liter of Rhodamine WT.

Between early June and mid-November 1983, no traces were initiated. A drought beginning in May and ending in October brought karst groundwater movement to a near halt. Dye from two traces in May and June did not adequately clear from the groundwater system until early fall.

DESCRIPTIONS OF INDIVIDUAL DYE TRACES

Figure 15 shows the injection and recovery sites of all dye traces. The straight lines connecting the injection sites with the recovery sites do not indicate the actual paths of groundwater movement. The actual path that groundwater follows from sinkhole to resurgence is probably anything but a straight line. During certain dye traces, dye-recovery packets were placed in cave streams to attempt to in some fashion to determine the actual path of groundwater movement. These traces will be discussed in later sections of the report. Table 1 lists physical data of the dye traces including travel distance, gradient, and velocity.

Jerry Lawrence Sink Trace, COP #1 (37°43'48" N, 89°52'33" W)

Jerry Lawrence Sink is an eastward extension of a large, shallow uvala in the western part of Perryville. Before extensive modification and drainage improvement, the sinkhole was subject to flooding after heavy rainfall. On March 23, 1983, at about 1600 hours, 3 liters of Rhodamine WT 20% dye was injected into a vertical concrete pipe in the base of the broad sinkhole. About 1200 gal of water was pumped into the pipe immediately after dye injection. The dye resurfaced between March 23 and April 1, 1983 at 3 locations: Mertz Resurgence, Doc White Spring, and Circle Drive Resurgence. The trace was made during a period of fairly wet weather. Ample recharge caused Circle Drive Resurgence to flow. Dye was detected until about April 21, 1984.

Shoe Factory Sink Trace, COP #2 (37°43'19" N, 89°52'16" W)

The sinkhole where this trace originated is used as a city park and a parking lot for International Shoe Company. Three liters of Rhodamine WT 20% was injected into a concrete pipe in the throat of the sink on May 25, 1983 at 1145 hrs. The rodding truck added approximately 1500 gal of water after the dye was injected. The dye was recovered at Clubhouse Resurgence along a tributary of Spring Branch between May 27 and June 8, 1983. Location of the resurgence was unknown before the trace. Dye-recovery packets had been placed at two bridges on Spring Branch, one upstream of the resurgence, the other downstream. Dye was detected continuously in the resurgence until about February 10, 1984, about 9 months after the trace began and intermittently thereafter.

School Street Trace, COP #3 (37°43'46" N, 89°52'26" W)

On June 10, 1983 at about 1300 hrs, 4 lbs of fluorescein dye was injected into a sinkhole next to a sewer-lift station on School Street in Perryville. Dye was recovered between June 15 and July 1, 1983 at three locations: Circle Drive Resurgence, Mertz Resurgence, and Doc White Spring. During the sampling interval between July 1 and August 3, fluorescein dye was recovered at Clubhouse Resurgence. However, the previous sample from Clubhouse Resurgence was negative as were samples after August 3. Fluorescein was continuously detectable at Mertz Resurgence and Doc White Spring for several months after August 3, but none was detected at Clubhouse Resurgence. The fluorescent material detected between July 1 and August 3 at Clubhouse Resurgence was probably from some source other than the School Street dye trace.

City Park Trace, COP #4 (37°43'24" N, 89°51'01" W)

The Perryville City Park, on the southeast side of town along Highway 61, makes wise use of a series of broad, shallow sinkholes. Picnic grounds and ball diamonds are little affected by sinkhole flooding. On November 17, 1983 at 1330 hrs, 1 liter of Rhodamine WT 20% dye was injected into the throat of a sinkhole

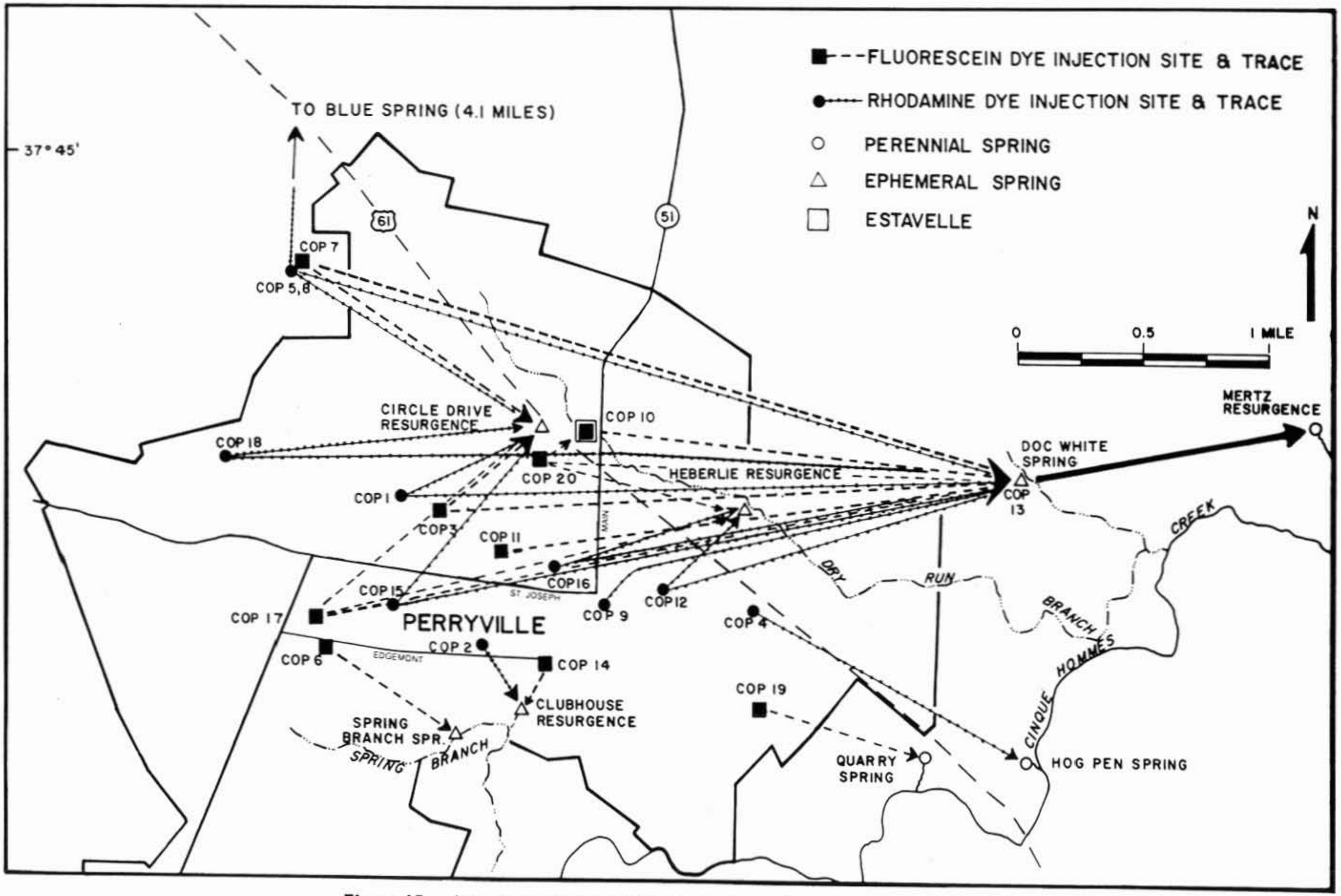


Figure 15 -- Injection and recovery sites for dye traces in the Perryville karst area.

TABLE 1 – Physical data of dye traces

	INJECTION DATA				RECOVERY DATA						
Name and reference number	Location (long.–lat.)	Elevation (ft msl)	Time and date	Tracing agent and amount	Name	Location (long.–lat.)	Date of detection	Straight-line distance (ft)	Elevation (ft msl)	Gradient (ft/mi)	Minimum velocity (ft/day)
Jerry Lawrence Sink Trace, COP #1	37°43'48" N, 89°52'33" W	560	1600 hrs. 3-23-83	Rhodamine WT 20% 3 l	Mertz Resurgence	37°44'6" N, 89°48'36" W	Between 3-23-83 & 4-1-83	19,008	400	44.4	2,112
					Doc White Spring	37°43'54" N, 89°49'52" W	Between 3-21-83 & 3-31-83	12,989	480	32.5	1,624
					Circle Drive Resurgence	37°44'4" N, 89°51'58" W	Between 3-31-83 & 4-12-83	3,200	518	69.3	169
Shoe Factory Trace, COP #2	37°43'19" N, 89°52'16" W	560	1145 hrs. 5-25-83	Rhodamine WT 20% 3 l	Clubhouse Resurgence	37°43'7" N, 89°52'6" W	Between 5-27-83 & 6-6-83	1,500	510	176.0	125
School Street Sink Trace, COP #3	37°43'46" N, 89°52'26" W	552	1300 hrs. 6-10-83	Fluorescein 4 lbs	Mertz Resurgence	37°44'6" N, 89°48'36" W	Between 6-15-83 & 7-1-83	18,500	400	43.4	881
					Doc White Spring	37°43'54" N, 89°49'52" W	Between 6-15-83 & 7-1-83	12,300	480	30.9	585
					Circle Drive Resurgence	37°44'4" N, 89°51'58" W	Between 6-15-83 & 7-1-83	2,800	518	64.1	133
City Park Sink Trace, COP #4	37°43'24" N, 89°51'1" W	505	1330 hrs 10-17-83	Rhodamine WT 20% 1 l	Hog Pen Spring	37°42'56" N, 89°49'49" W	Between 10-17-83 & 10-29-83	6,500	420	69.0	542
Zahner Sink Trace #1, COP #5	37°44'35" N, 89°53'7" W	580	1300 hrs 1-25-84	Rhodamine WT 20% 1 l	Blue Spring	37°48'9" N, 89°53'42" W	Between Dec. 1983 & 3-7-84	21,700	420	38.9	516
Edgemont Sink Trace, COP #6	37°43'17" N, 89°52'55" W	611	1400 hrs. 1-25-84	Fluorescein 1 lb	Spring Branch Spring	37°42'59" N, 89°52'20" W	Between 1-25-84 & 2-2-84	3,300	500	177.6	412
Zahner Cave Trace, COP #7	37°44'38" N, 89°52'58" W	565	1630 hrs 3-28-84	Fluorescein 3 lbs	Circle Drive Resurgence	37°44'4" N, 89°51'58" W	0900 hrs 3-29-84	6,200	518	40.0	9,018
					Doc White Spring	37°43'54" N, 89°49'52" W	0930 hrs 3-29-84	16,000	480	28.1	22,588
					Mertz Resurgence	37°44'6" N, 89°48'36" W	Between 3-28-84 & 4-4-84	21,120	400	41.3	3,017
					Hog Pen Spring	37°42'56" N, 89°49'49" W	Between 3-28-84 & 4-4-84	18,000	420	42.5	2,572
					Heberlie Resurgence	37°43'46" N, 89°51'4" W	Between 3-28-84 & 4-25-84	10,700	495	34.5	382

Table 1 (cont.)

	INJECTION DATA				RECOVERY DATA						
Name and reference number	Location (long.—lat.)	Elevation (ft msl)	Time and date	Tracing agent and amount	Name	Location (long.—lat	Date of detection	Straight-line distance (ft)	Elevation (ft msl)	Gradient (ft/mi)	Minimum velocity (ft/day)
Zahner Sink Trace #2, COP #8	37°44'35" N, 89°53'7" W	580	0930 hrs 3-29-84	Rhodamine WT 20% 2 l	Circle Drive Resurgence	37°44'4" N, 89°51'58" W	Between 3-29-84 & 3-31-84	6,500	518	50.4	3,250
					Doc White Spring	37°43'54" N, 89°49'52" W	Between 3-29-84 & 4-3-84	16,300	480	32.4	3,260
					Mertz Resurgence	37°44'6" N, 89°48'36" W	Between 3-29-84 & 4-4-84	21,200	400	44.8	3,533
					Blue Spring	37°48'9" N, 89°53'42" W	Between 3-29-84 & 4-4-84	21,700	420	38.9	3,617
Parking Lot Sink Trace, COP #9	37°43'27" N, 89°51'42" W	566	1115 hrs 4-25-84	Rhodamine WT 20% 1.5 l	Doc White Spring	37°43'54" N, 89°49'52" W	4-25-84 & 5-2-84	9,250	480	49.1	1,321
					Mertz Resurgence	37°44'6" N, 89°48'36" W	Between 4-25-84 & 5-2-84	15,400	400	56.9	2,200
Dry Run Branch Estavelle Trace, COP #10	37°44'2" N, 89°51'47" W	515	1030 hrs 4-30-84	Fluorescein 2 lbs	Doc White Spring	37°43'54" N, 89°49'52" W	Between 4-30-84 & 5-2-84	9,250	480	20.0	4,625
					Mertz Resurgence	37°44'6" N, 89°48'36" W	Between 4-30-84 & 5-2-84	15,200	400	39.9	7,600
Oster Sink Trace, COP #11	37°43'27" N, 89°52'10" W	550	1315 hrs 6-6-84	Fluorescein 1 lb	Doc White Spring	37°43'54" N, 89°49'52" W	Between 6-6-84 & 6-12-84	11,150	480	33.1	1,858
					Mertz Resurgence	37°44'6" N, 89°48'36" W	Between 6-6-84 & 6-12-84	17,300	400	45.8	2,883
					Circle Drive Resurgence	37°44'4" N, 89°51'58" W	Between 6-27-84 & 8-29-84	2,800	518	60.3	33
Ste. Marie Pit Trace, COP #12	37°43'33" N, 89°51'21" W	556	1340 hrs 6-6-84	Rhodamine WT 20% 1 l	Doc White Spring	37°43'54" N, 89°49'52" W	Between 6-6-84 & 6-12-84	7,500	480	53.5	1,250
					Mertz Resurgence	37°44'6" N, 89°48'36" W	Between 6-6-84 & 6-12-84	13,600	400	60.5	2,267
					Heberlie Resurgence	37°43'46" N, 89°51'4" W	6-6-84 & 8-29-84	2,500	495	129	30
Doc White Spring Sink Trace, COP #13	37°43'54" N, 89°49'52" W	480	1445 hrs 7-2-84	Fluorescein 1/3 lb	Mertz Cave	37°44'7" N, 89°51'33" W	Between 7-2-84 & 0945 hrs 7-3-84	4,100	420	77.3	5,179
					Mertz Resurgence	37°44'6" N, 89°48'36" W	Between 7-2-84 & 7-3-84	6,100	400	69.2	7,705

Table 1 (cont.)

INJECTION DATA					RECOVERY DATA						
Name and reference number	Location (long.–lat.)	Elevation (ft msl)	Time and date	Tracing agent and amount	Name	Location (long.–lat.)	Date of detection	Straight-line distance (ft)	Elevation (ft msl)	Gradient (ft/mi)	Minimum velocity (ft/day)
Lurk Sink Trace, COP #14	37°43'14" N, 89°51'58" W	570	1330 hrs 7-3-84	Fluorescein 2/3 lb	Clubhouse Resurgence	37°43'7" N, 89°52'6" W	Between 7-3-84 & 7-12-84	1,100	510	288	122
Zeno Street Sink Trace, COP #15	37°43'26" N, 89°52'38" W	590	1345 hrs 7-3-84	Rhodamine WT 20% 1 l	Mertz Resurgence	37°44'6" N, 89°48'36" W	Between 7-3-84 & 7-12-84	19,700	400	50.9	2,189
					Doc White Spring	37°43'54" N, 89°49'52" W	Between 7-12-84 & 7-27-84	13,500	480	43.0	563
					Circle Drive Resurgence	37°44'4" N, 89°51'58" W	Between 7-3-84 & 8-29-84	4,900	518	77.6	86
Great Perry Cave Trace, COP #16	37°43'35" N, 89°51'56" W	547	1310 hrs 9-20-84	Rhodamine WT 20% 1 l	Doc White Spring	37°43'54" N, 89°49'52" W	Between 9-20-84 & 9-25-84	10,100	480	35.0	2,020
					Heberlie Resurgence	37°43'46" N, 89°51'4" W	Between 9-20-84 & 9-25-84	4,300	495	63.9	860
					Mertz Resurgence	37°44'6" N, 89°48'36" W	Between 9-20-84 & 10-12-84	16,200	400	47.9	736
Rozier Sink Trace, COP #17	37°43'23" N, 89°52'59" W	615	1400 hrs 9-20-84	Fluorescein 1 lb	Circle Drive Resurgence	37°44'4" N, 89°51'58" W	Between 9-20-84 & 9-25-84	6,300	518	81.3	1,260
					Heberlie Resurgence	37°43'46" N, 89°51'4" W	Between 9-20-84 & 9-25-84	9,500	495	66.7	1,900
					Doc White Spring	37°43'54" N, 89°49'52" W	Between 9-20-84 & 9-25-84	15,300	480	46.6	3,060
					Mertz Resurgence	37°44'6" N, 89°48'36" W	Between 9-20-84 & 10-12-84	21,400	400	53.0	973
Rob Roy Sink Trace, COP #18	37°43'56" N, 89°53'23" W	610	1340 hrs 10-25-84	Rhodamine WT 20% 1 l	Circle Drive Resurgence	37°44'4" N, 89°51'58" W	Between 10-25-84 & 11-2-84	6,700	518	72.5	837
					Doc White Spring	37°43'54" N, 89°49'52" W	Between 10-25-84 & 11-2-84	16,900	480	40.6	2,113
					Mertz Resurgence	37°44'6" N, 89°48'36" W	Between 10-25-84 & 11-16-84	23,000	400	48.2	1,045

Table 1 (cont.)

	INJECTION DATA				RECOVERY DATA							
Name and reference number	Location (long.–lat.)	Elevation (ft msl)	Time and date	Tracing agent and amount	Name	Location (long.–lat.)	Date of detection	Straight-line distance (ft)	Elevation (ft msl)	Gradient (ft/mi)	Minimum velocity (ft/day)
BQT Trace, COP #19	37°43'4" N, 89°51'2" W	520	1430 hrs 10-25-84	Fluorescein 1 lb	Quarry Spring	37°42'56" N, 89°50'16" W	Between 10-25-84 & 1030 hrs 10-26-84	3,800	460	83.4	4,560
Hospital Sink Trace, COP #20	37°43'58" N, 89°52' W	539	11-1-84	Fluorescein ½ lb	Dry Run Branch Estavelle	37°44'2" N, 89°51'47" W	Between 11-1-84 & 11-2-84	1,100	510	139.2	1,100
					Heberlie Resurgence	37°43'46" N, 89°51'4" W	Between 11-1-84 & 11-2-84	4,600	495	50.5	4,600
					Mertz Resurgence	37°44'6" N, 89°48'36" W	Between 11-1-84 & 11-16-84	16,200	400	45.3	1,013
					Doc White Spring	37°43'54" N, 89°49'52" W	Between 11-1-84 & 11-26-84	10,200	480	30.5	392

in the park. Water was flowing into the sink at the time. Dye was first detected at Hog Pen Spring between November 17 and November 29, 1983 and remained in the water in detectable amounts until February 15, 1984.

Zahner Sink Trace, COP #5 (37°44'35" N, 89°53'07" W)

The sinkhole where this trace was initiated is one of several small sinkholes in an uvala just northwest of Perryville, along Sycamore Road. On January 25, 1984 at 1300 hrs, 1 liter of Rhodamine WT 20% dye was injected into a small sinkhole adjacent to Sycamore Road. Runoff from melting snow carried the dye into the subsurface. The entrance to Zahner Cave is in the same uvala. The southeast trend of the cave toward Circle Drive Resurgence indicats probable dye recovery at springs along Cinque Hommes Creek. Dye-recovery packets collected at Mertz Resurgence, Doc White Spring, Circle Drive Resurgence, and Hog Pen Spring for the next month showed no dye, although the weather favored groundwater recharge. A dye-recovery packet collected from Blue Spring on March 7 showed positive Rhodamine content. The March 7 to March 12 sampling interval at Blue Spring showed no more dye present. The trace was repeated; results are discussed later in this section of the report.

Edgemont Sink Trace, COP #6 (37°43'17" N, 89°52'55" W)

On January 25, 1984 at 1400 hrs, 1 lb of fluorescein dye was introduced into a sinkhole on the south side of Edgemont Boulevard in southwestern Perryville. The sink contains a steel pipe with trash rack in the throat. Runoff water flowing into the sink, augmented with several hundred gallons from the rodding truck, was used to wash the dye into the subsurface. Dye was first detected between January 25 and February 2, 1984 at Spring Branch Spring.

Zahner Cave Trace, COP #7 (37°44'38" N, 89°52'58" W)

Zahner Cave can be entered through any of several shallow, linear sinkholes along the east side of an uvala west of Perryville. The entrances are along a solution-enlarged joint which daylights (surfaces) in several places. A short crawlway and climb through wedged boulders leads to the cave stream. The cave contains about 10,000 ft of mapped passage and trends southeast toward Circle Drive Resurgence. On March 28, 1984 at 1630 hrs, 3 lbs of fluorescein dye was introduced into the cave stream, which was flowing about 0.3 ft^3/sec. The dye was quickly carried downstream.

Dye was recovered less than 16.5 hours later at Circle Drive Resurgence, 6200 ft away. Dye was also recovered between March 28 and April 25, 1984 at Heberlie Resurgence, a small intermittent spring 4800 ft downstream from Circle Drive Resurgence. Dye was recovered from Doc White Spring, 3.03 mi from the injection point, within 17 hours after injection and at Mertz Resurgence between March 28 and April 4, 1984. Hog Pen Spring also had a positive fluorometric reading. The dye was injected at the end of a major storm. Numerous sinkholes were flooded and there was much groundwater recharge. Several springs that contained dye during the very high recharge period would probably not have been affected during normal flow periods; they include Hog Pen Spring and Heberlie Resurgence. Apparently, during periods of very high groundwater recharge, upper level conduits can channel water to a number of widely separated karst groundwater outlets.

Zahner Sink Trace (repeat), COP #8 (37°44'35" N, 89°53'07" W)

This trace is a repeat of the earlier (January 25, 1984) Zahner sink trace. At 0930 hrs on March 29, 1984, 2 liters of Rhodamine WT 20% dye was injected into the base of Zahner Sink. The day before, when the Zahner Cave trace was initiated, this sinkhole was flooded. At the time of the trace, water had drained from the sinkhole, but much runoff from the adjacent county road ditch and hill slope was still entering the sink. On March 31, 1984, dye was observed exiting from Circle Drive Resurgence (Yokum, 1984, pers. comm.). Dye was recovered between March 29 and April 4, 1984 at Blue Spring. Mertz Resurgence and Doc White Spring received Rhodamine dye from this trace during the same sampling interval. The earlier Zahner Sink trace showed dye flowing only to Blue Spring. As with the Zahner Cave trace, however, high groundwater stages apparently profoundly affect the direction of groundwater movement. Apparently, groundwater levels due to excessive recharge in Zahner Sink were high enough to cause groundwater movement not only to the northeast, as before, but also to the southeast, probably via Zahner Cave. Groundwater stages or recharge amounts must therefore be considered a factor in the ultimate direction of groundwater movement in the Perryville karst.

Parking Lot Sink Trace, COP #9 (37°43'27" N, 89°51'42" W)

In the southeast corner of a city parking lot just southeast of the Perry County Courthouse in Perryville is a manhole that, when the cover is removed, allows entry into a vertical pipe that channels stormwater runoff into a low cave. On April 25, 1984 at 1115 hrs, 1.5 liters of Rhodamine WT 20% dye and 1500 gal of water were injected into the cave. Dye reappeared between April 25 and May 2, 1984 at Doc White Spring and Mertz Resurgence.

Dry Run Branch Estavelle Trace, COP #10 (37°44'02" N, 89°51'47" W)

As previously discussed, the upper watershed of Dry Run Branch contains many karst features associated with both groundwater recharge and discharge. On April 30, 1984 at 1030 hrs, 2 lbs of fluorescein dye was injected into the estavelle in the channel of Dry Run Branch, about 300 ft upstream from the Highway 51 crossing. Stormwater runoff was flowing down Dry Run Branch, and all the water was disappearing into the subsurface at the estavelle. Dye was recovered between April 30 and May 2 at Doc White Spring and Mertz Resurgence. No dye was detected in small springs downstream of the estavelle on Dry Run Branch.

Oster Sink Trace, COP #11 (37°43'27" N, 89°52'10" W)

Oster Sink is a sinkhole with poor drainage characteristics, in the west-central part of Perryville. After heavy rainfall, the sink commonly fails to channel all its drainage into the subsurface and causes local flooding. On June 6, 1984 at 1315 hrs, 1 lb of fluorescein dye was injected into the sinkhole. There was some ponded water in the sink when dye was injected, and about 500 gallons of water was added from a truck. The additional water caused water level in the sink to rise slightly and stabilize as water flowed from the sink through bedding plane openings in its sides. The dye reappeared between June 6 and June 12, 1984 at Doc White Spring and Mertz Resurgence. Dye-recovery packets placed July 3, 1984 in Streiler City Cave where water from North Street Cave enters, contained dye when collected July 22, 1984.

Ste. Marie Pit Trace, COP #12 (37°43'33" N, 89°51'21" W)

Ste. Marie Pit, on the south side of Ste. Marie Street, about 6 blocks east of Perryville City Hall, is on the edge of a small sinkhole and consists of a vertical shaft some 20 ft deep, the upper 10 ft being cased in concrete. The original shape of the sinkhole has been altered by fill material placed in the sink during home construction. On June 6, 1984 at 1340 hrs, 1 liter of Rhodamine WT 20% dye was injected into the pit, followed by 500 gal of water. A small stream flowed across the base of the pit at the time. Dye was recovered between June 6 and June 12 at Doc White Spring and Mertz Resurgence. Dye recovered at Heberlie Resurgence on August 30, 1984 probably came from this trace. Late summer 1984 was fairly dry, and the packet was in place for several months.

Doc White Spring Sink Trace, COP #13 (37°43'54" N, 89°51'58" W)

Doc White Spring, an intermittent resurgence, typically flows during fall, winter, and spring, but dry weather causes flow to cease. About 100 ft east of the spring is a small sinkhole, about 4 ft wide and 4 ft deep, across the base of which, water moves, even when the spring itself is not flowing. On July 2, 1984 at 1445 hrs, when spring was not flowing, 1/3 lb of fluorescein dye was introduced into the sinkhole. Dye was detected less than 19 hours later in Mertz Cave stream, 4100 ft east of the injection site and also at Mertz Resurgence.

Lurk Sink Trace, COP #14 (37°43'14" N, 89°51'58" W)

On July 3, 1984 at 1330 hrs, 2/3 lb of fluorescein dye was introduced into a concrete-walled sinkhole throat in an alley near Edgemont Blvd. Water was flowing across the base of the sinkhole, and no additional water was added. The dye first reappeared at Clubhouse Resurgence between July 3 and July 12, 1984.

Zeno Street Sink Trace, COP #15 (37°43'26" N, 89°52'38" W)

In the southwest part of Perryville, a karst valley consisting of a northward-trending linear row of shallow sinks starting about Edgemont Boulevard drains several acres. Several of the sinks have been modified to facilitate drainage. On July 3, 1984 at 1345 hrs, 1 liter of Rhodamine WT 20% dye was injected into the throat of a sinkhole along Zeno Street. Some water was moving through the sink at the time. Dye was recovered between July 3 and July 13, 1984 at Mertz Resurgence. Between July 13 and July 27, Doc White Spring flowed briefly and dye was recovered there. Dye passed through Streiler City Cave between July 3 and July 22, 1984. The dye-recovery packet in Streiler City Cave was placed where water entered the cave stream from a low, bedding-plane opening on the south side of the cave, about 200 ft downstream from the entrance. The water is believed to be from North Street Cave.

Great Perry Cave Trace, COP #16 (37°43'35" N, 89°51'56" W)

The entrance to Great Perry Cave is about 1 block west of City Hall in Perryville, at the base of a large sinkhole. The shallow entrance pit is developed along a joint and is covered by a steel grate that apparently serves two purposes: it prevents debris from washing into the cave and prevents entry. Scott House (1975, MSS Cave Files) reports gasoline and diesel fuel entering the cave from nearby storage tanks. On September 20, 1984 at 1310 hrs, 1 liter of Rhodamine WT 20% dye was injected into the entrance of the cave (fig. 16). The dye was recovered at Heberlie Resurgence and Doc White Spring, between September 20 and September 25, 1984, and Mertz Resurgence, between September 20 and October 13, 1984.

Figure 16 -- Bob Schumer and Cynthia Endicott injecting Rhodamine WT dye into the sinkhole entrance of Great Perry Cave.

Rozier Sink Trace, COP #17 (37°43'23" N, 89°51'59" W)

Rozier Sink, a shallow, broad sinkhole with several throats, is in southwestern Perryville, at the upstream end of a shallow karst valley. On September 20, 1984 at 1400 hrs., 1 lb of fluorescein dye was injected into a throat of the sink. About 1800 gal of water was added to wash the dye into the subsurface. Downstream of the sink about 1100 feet north, is a concrete drop-inlet box in the base of a small sinkhole that tends to drain poorly and may discharge water after heavy precipitation. About 250 ft northeast of the drop-inlet box, on the other side of St. Joseph Street, is Log Cabin Spring, a small intermittent groundwater outlet. There is another spring, Grand Street Spring, about 1000 ft northeast of the drop-inlet on St. Josept Street, near the intersection of Grand and Moulton Streets. Many years ago, the spring was channelled into the street and, in 1984, into a drain pipe which trends northeast and now ends in Jerry Lawrence Sink.

Dye-recovery packets were placed in the drop-inlet box, at Log Cabin Spring, and in the large drain pipe downstream of Grand Street Spring. Dye-recovery packets were also in place at the usual monitoring sites. Dye from Rozier Sink was recovered at the drop-inlet box on St. Joseph Street and in the pipe downstream of Grand Street Spring, between September 20 and 25, 1984. Log Cabin Spring showed no dye. Fluorescein was also recovered at Circle Drive Resurgence, Heberlie Resurgence, and Doc White Spring, between September 20 and 25, 1984, and Mertz Resurgence between September 20, and October 12, 1984.

Rob Roy Sink Trace, COP # 18
(37°50'06" N, 89°53'23" W)

On October 25, 1984 at 1340 hrs, 1 liter of Rhodamine WT 20% dye was introduced into a small sinkhole in southwestern Perryville, just west of Sycamore Lane. Approximately 1 gpm of water was flowing into the sink at the time of injection. Dye was recovered between October 25 and November 2, 1984 at three locations: Circle Drive Resurgence, Doc White Spring, and Mertz Resurgence. Dye was first visually detected at an unnamed spring a few hundred feet east of the injection site. Flow from the spring travels northeast a few hundred feet, loses into a sinkhole, and rises again at another small spring a short distance away. The water then enters another sinkhole near an electric substation.

BQT Trace, COP #19
(37°43'04" N, 89°51'02" W)

The Bruckerhoff, Quatman, Tlapek (BQT) dye trace originated in a small sinkhole in a large field southeast of the Perryville City Park. At the time of injection, the field containing the sinkhole was water-saturated, and approximately 50 gpm was draining into the sinkhole.

One pound of fluorescein dye was injected into the sinkhole, at 1430 hrs, on October 25, 1984. The runoff from the field quickly carried the dye into the subsurface. Dye was detected visually at Quarry Spring the next morning, October 26, at 0920 hrs. However, it probably reappeared several hours before it was first observed.

Hospital Sink Trace, COP #20
(37°43'58" N, 89°52'00" W)

On November 1, 1984 at approximately 1200 hrs, ½ lb of fluorescein dye was introduced into a sinkhole just northwest of the Perry County Hospital in Perryville. This trace was intended to help determine the recharge area of Dry Run Branch Estavelle. Dye was injected during a period of heavy rainfall and reappeared the next day, November 2, at the estavelle. Dye was also recovered at Heberlie Resurgence, Doc White Spring, and Mertz Resurgence.

DISCHARGE CHARACTERISTICS OF SPRINGS AND RESURGENCES IN THE STUDY AREA

The discharge characteristics of a spring or resurgence is a reflection of the groundwater supply system, the mode of groundwater recharge, and local climate.

Recharge can be broadly categorized into either discrete or diffuse recharge. Diffuse recharge is provided by precipitation falling over a broad area and infiltrating through the soil materials and rock until it reaches the water table. Discrete recharge is the more concentrated movement of water from the surface to the groundwater system. The major mechanisms of discrete recharge are sinkholes, losing streams, swallets, and estavelles, all features that efficiently channel water from the surface to the subsurface.

Water provided by diffuse recharge is commonly termed "water in storage." Though moving, and part of a dynamic system, the rate of movement is relatively low. Such water is allowed longer residence time in the groundwater system and tends to reach chemical equilibrium with respect to the earth materials more closely than discrete recharge. Water in storage provides base flows for springs and gaining streams and is typically utilized by water-supply wells.

"Water in transit" is provided by discrete recharge, which enters the groundwater system quickly and travels with much less resistance than diffuse recharge, through the conduit system feeding a spring or resurgence. Its lower residence time allows less solutioning to take place, so typically this water does not reach equilibrium with the earth materials. Though the water is usually lower in dissolved solids, it can contain more suspended sediment and contaminants.

Based upon recharge type and the characteristics of the conduit systems feeding them, different

springs respond differently to recharge. High-storage springs have discharges that do not vary greatly in response to local precipitation. They typically receive diffuse recharge and have relatively uniform water quality. Discharge changes occur, but a sudden thunderstorm does not cause flows to increase dramatically in a few hours. Rather, the discharge might increase gradually for several days before slowly declining. High-transit springs, which occupy the other end of the discharge-character spectrum, receive immediate and direct recharge from discrete recharge features. Their flows may vary from trickles during droughts to raging torrents after heavy rainstorms. As a result, water quality is also extremely variable. The flow system feeding a high-transit spring is quite open, allowing large amounts of water to enter the groundwater system quickly and also to drain quickly.

Thus, the discharge character of a spring relates to how water is recharged, integration of the groundwater flow system, the size of the area providing recharge, and local climate.

Flows of major springs and resurgences in the study area were measured several times under differing climatic conditions. A summary of the flow data is shown in table 2. In some cases, especially after heavy rainfall, it was physically impossible to measure flows of some springs, due to flooding of the receiving streams or water depths in the spring branches. Several estimated flow values appear in table 2. Of course, these must be considered less accurate than the measured values but are provided to illustrate magnitude of some spring flows during very wet weather.

All major springs and resurgences in the study area are high-transit springs and have dry weather flows ranging from zero to about 2 ft^3/sec. For Mertz Resurgence, the largest groundwater outflow point on Cinque Hommes Creek and in the study area, the minimum measured flow in August 1984 after a two-month dry spell, was 1.99 ft^3/sec. After heavy rain, the flow has been visually estimated at more than 100 ft^3/sec. From the flow data alone, it is apparent that the spring drains a large portion of the Perryville karst area and has an extensive conduit system channelling water to the spring.

The flow of Doc White Spring is quite variable, ranging from zero during dry summer periods to more than 40 ft^3/sec after heavy rain. The discharge character of the spring changed during this study. In early September 1984, a backhoe was used to open the spring, thereby exposing a rise pool in a shallow cave. Since then, the spring tends to flow less often but with higher peak discharges. Apparently, before the spring was opened, debris blocking the orifice constricted flow and caused ponding on the upstream side of the conduit, but this no longer occurs.

Hog Pen Spring, less variable than Doc White Spring, has a low but well-sustained base flow. In August 1984, during very dry weather, it was measured at 0.104 ft^3/sec. Peak observed flow of the spring during the study was about 20 ft^3/sec, an estimate including flow from numerous openings above and adjacent to the main spring, which were providing at least 50 percent of the discharge.

Circle Drive Resurgence is a high-stage groundwater overflow that functions only briefly after heavy rain. When it was gaged after about 1.5 in. of rain in the preceding 24 hours, the flow was 8.2 ft^3/sec. After a heavy rain, the flow was estimated at 40 ft^3/sec, but after 18 hours, flow had receded to about 5 ft^3/sec. The resurgence also functions as a recharge point. Surface runoff from the area around the resurgence flows into the cave if rainfall has been insufficient to cause the resurgence to discharge.

Quarry Spring has a well-sustained base flow, which was once measured at 0.15 ft^3/sec. Observations during the current study indicated a low flow of about 0.03 ft^3/sec. Quarry Spring appears to have the most uniform flow of any spring in the study area.

Club House Resurgence was not measured during the current study. Due to its location and spring outlet characteristics, accurate gaging was not practical. After heavy rain, peak discharge is about 10 ft^3/sec; during dry weather, flow nearly stops.

Along Blue Spring Branch, Blue Spring is the largest groundwater outflow point. During very dry weather, its flow has been measured at 0.3 ft^3/sec, but high flows are estimated to exceed 40 ft^3/sec. During late summer 1984, flow nearly stopped. The spring is very close to the channel of Blue Spring Branch and after heavy precipitation, high stream stage hampers good visual estimations and makes direct measurements nearly impossible.

Blue Spring Resurgence was observed flowing only once during this study, at which time it was discharging approximately 0.5 ft^3/sec. Flow occurred at other times, as shown by high-water marks in the

TABLE 2 – Discharge data for selected springs in the study area

	Date	Discharge (ft^3/sec)	Rainfall previous day (in.)	Rainfall previous week (in.)
Mertz Resurgence	4-21-83	8.13	0	1.65
	3-12-84	6.70	0.25	0.24
	3-28-84	>100 e	1.62	0.62
	8-9-84	1.99	0.55	0.36
Doc White Spring	4-14-83	15.7	1.46	1.88
	3-13-84	2.49	0.11	0.25
	3-28-84	40 e	1.62	0.62
	8-9-84	0	0.55	0.36
Hog Pen Spring	4-14-83	1.58	1.46	1.88
	3-14-84	0.708	0	0.36
	3-28-84	20 e	1.62	0.62
	8-9-84	0.104	0.55	0.36
Quarry Spring	3-14-84	0.151	0	0.36
	8-9-84	0.03 e	0.55	0.36
Clubhouse Resurgence	8-9-84	0.04 e	0.55	0.36
Circle Drive Resurgence	4-14-83	8.20	1.46	1.88
	3-12-84	0	0.25	0.24
	3-28-84	40 e	1.62	0.62
	3-29-84	5 e	0	2.24
	8-9-84	0	0.55	0.36
Blue Spring	4-14-83	20.5	1.46	1.88
	3-12-84	5.29	0.25	0.24
	3-28-84	60 e	1.62	0.62
	8-9-84	0	0.55	0.36
Blue Spring Resurgence	4-14-83	0	1.46	1.88
	3-12-84	0	0.25	0.24
	3-29-84	0.5 e	0	2.24
	8-9-84	0	0.55	0.36
Keyhole Spring	4-14-83	2.16	1.46	1.88
	3-12-84	0.470	0.25	0.24
	8-9-84	0.15 e	0.55	0.36
Keyhole Resurgence	4-14-83	0	1.46	1.88
	3-12-84	0.1 e	0.25	0.24
	8-9-84	0	0.55	0.36
Ball Mill Spring	4-14-83	4.30	1.46	1.88
Ball Mill Resurgence	4-14-83	0		

resurgence branch, but the resurgence functions so briefly that the peaks are missed if it is not visited within a few hours after rain stops. Combined peak flow of Blue Spring and Blue Spring Resurgence is estimated to exceed 100 ft^3/sec.

Keyhole Resurgence, immediately downstream of Blue Spring, has been observed discharging water only a few times during the study, but the flows were always low, less than 1 ft^3/sec. Vineyard (1984, pers. comm.) visited the resurgence in 1968, after very heavy rainfall, and estimated the flow to be 50 ft^3/sec. Keyhole Spring has a low but well-sustained base flow but also, apparently, a fairly low peak discharge. Peak flow measured during this study was 1.88 ft^3/sec during fairly wet weather.

Ball Mill Spring was measured once at 4.30 ft^3/sec during wet weather and, like Keyhole Spring, has a low but well-sustained base flow. Ball Mill Resurgence was not observed flowing during the study. Vineyard (1984, pers. comm.) visited it in 1968, after heavy rainfall, and estimated flow to be 60 ft^3/sec. However, high-water marks and local reports indicate flow can exceed 180 ft^3/sec during peak rainfall periods.

KARST GROUNDWATER QUALITY IN THE STUDY AREA

The quality of water issuing from a spring, like its quantity, reflects the character of its recharge area. Water quality also partly depends on the type of rock or earth materials the water contacts. All water flowing from springs in the study area originates as local precipitation. Table 3 shows water quality of springs and resurgences in the area. Extensive, repetitive water sampling was beyond the scope of the current study, but the information gathered from limited sampling is quite useful in establishing recharge characteristics and in showing how human activities affect water quality.

Groundwater temperature in most areas is usually fairly constant and roughly equal to the mean annual temperature of the individual area. In the study area, spring water temperature was discovered to be quite variable, measured values ranging from 49°F to 67°F. Mean annual temperature of the area is about 59°F. The wide temperature range is easily explained by the nature of the karst groundwater system. The spring systems are very open; most consist of caves, with recharge primarily from stormwater runoff entering sinkholes. In summer, therefore, warm rain water causes water temperatures to rise. Winter runoff from either rain or snowmelt is much colder than mean annual temperature, and causes spring water temperature to fall. Of course, all southern Missouri springs are subject to the same climatic changes. Because of residence time, however, most other springs do not show the wide fluctuations in water temperature. Most Ozark springs receive more diffuse recharge than those in the study area. In most of the Ozarks, recharge remains in the spring system much longer than in the study area. The earth serves as a heat sink, allowing recharge to equilibrate with mean annual temperature. In the study area, recharge is mostly discrete recharge and, based on dye-trace information, residence time varies from a few hours, during peak recharge periods, to a few days, during dry weather.

Many dissolved constituents in spring water reflect the composition of earth materials the water has contacted. As would be expected, all spring water in the study area is a calcium-magnesium-bicarbonate type, because the bedrock is dominantly limestone and dolomite, both carbonate rocks. Sodium occurs in expected levels, but potassium levels for some springs are somewhat higher than expected, probably due to contamination by agricultural fertilizers and organic waste. Total iron and total manganese levels are relatively high, but only part of the iron and manganese is dissolved; the rest is contained in suspended sediment. Sulfate levels were less than 50 milligrams per liter (mg/l). Spring waters passing through fairly pure carbonate aquifers typically have lower sulfate content, generally about 10 mg/l, but carbonate rocks in the study area contain minor amount of shale that may cause increased sulfate levels.

TABLE 3 – Water quality of selected springs and resurgences

Values, unless otherwise noted, are milligrams per liter

Name of spring	Date	Discharge (ft^3/sec)	Water temperature (°F)	Air temperature (°F)	Specific conductance (µmho/cm)	Dissolved oxygen (mg/l)	Field pH	Alkalinity (as $CaCO_3$)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Total manganese (Mn)	Total iron (Fe)	Sulfate (SO_4)	Chloride (Cl)	Nitrite+Nitrate Nitrogen ($NO_2 + NO_3$) as N	Ammonia Nitrogen (NH_3) as N	Total dissolved solids (TDS)	Total hardness	Carbonate hardness	Non-carbonate hardness
Mertz Resurgence	3-13-84	6.70	52	30	690	6.8	7.6	251.2	293.9	6.1	93	19	18.9	2.5	0.06	0.50	19	25.0	–	–	430	311.5	251.2	60.3
	3-28-84	>100e	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.81	0.13	–	–	–	–
	8-9-84	1.99	57	72	610	–	7.3	251.2	306.3	0	85	20	17.0	5.5	0.24	3.60	11	23.5	6.4	0.08	426	301.5	251.2	50.3
Doc White Spring	3-13-84	2.49	52	35	740	4.0	7.1	210.5	256.7	0	63	27	11.9	3.1	0.03	0.45	32	69.5	–	–	435	269.3	210.5	58.8
	3-28-84	40e	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.60	0.81	–	–	–	–
	8-10-84	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hog Pen Spring	3-14-84	0.708	49	40	700	6.8	7.6	227.8	277.8	0	66	29	33.6	3.1	0.03	0.52	30	50.0	–	–	406	285.2	227.8	57.4
	3-28-84	20e	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.2	0.12	–	–	–	–
	8-9-84	0.104	58	78	600	–	7.0	215.6	262.9	0	58	29	16.5	6.75	0.44	5.15	23	37.0	1.9	0.06	414	274.2	215.6	58.6
Quarry Spring	3-14-84	0.151	53	40	700	–	7.5	245.1	298.8	0	70	34	22.0	2.3	0.05	0.80	42	28.0	–	–	413	316.3	245.1	71.2
	3-29-84	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3.2	0.07	–	–	–	–
	8-9-84	0.03e	56	76	710	–	7.05	300.0	365.8	0	66	42	15.0	2.2	0.02	0.26	25	18.0	3.8	0.01	459	338.2	300.0	38.2
Clubhouse Resurgence	8-9-84	0.04e	60	78	590	–	6.9	250.2	305.0	0	65	27	20.0	3.65	0.09	1.25	25	26.5	0.81	0.01	383	275.8	250.2	25.6
Circle Drive Resurgence	3-28-84	40e	–	–	–	–	–	48.8	59.5	0	18	5	3.2	4.35	0.33	8.5	2	1.5	<1	–	186	81.4	48.8	32.6
	8-9-84	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Blue Spring	3-12-84	5.29	53	30	570	4.5	7.2	193.2	235.6	0	55	28	17.9	2.2	0.02	0.21	16	22.5	–	–	376	253.0	193.2	59.8
	3-28-84	60e	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.2	0.18	–	–	–	–
	8-9-84	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Keyhole Spring	3-12-84	0.470	52	30	590	5.4	–	219.7	267.8	0	58	29	16.6	2.8	0.02	0.42	14	19.0	–	–	364	265.0	219.7	45.3
	8-9-84	0.15e	67	80	200	–	7.2	72.2	88.0	0	19	8	5.0	16.25	0.20	7.63	3	8.5	1.5	0.04	206	94.4	72.2	22.2
Keyhole Resurgence	3-12-84	0.1e	51	30	750	–	–	380.3	463.8	0	8.4	4.9	5.7	1.2	0.03	0.07	19	4.5	–	–	434	411.6	380.3	31.3
	8-9-84	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

e = estimated

Several dissolved constituents in the spring water can be linked to human activities in the study area. Nitrite, nitrate, and ammonia are nutrients that generally occur only in very low concentrations in unpolluted groundwater; the three can be considered a series. Ammonia is unstable in natural waters that contain appreciable dissolved oxygen. In the presence of oxygen, ammonia will form nitrite, also unstable if oxygen is present, and ultimately convert to nitrate. In spring waters of the study area, dissolved oxygen content, which was measured once during the study, ranged from 4.5 mg/l to 6.8 mg/l, somewhat low for spring water, but considering the nutrients in the water and the biological and chemical oxygen demand, not unreasonable. Nutrient values were determined twice for springs in the study area. Ammonia levels were somewhat high, ranging from 0.007 mg/l to 0.81 mg/l. Such levels, when considered with the ample dissolved oxygen, indicate very local sources of ammonia. Nitrite + nitrate values also reflect an abundant supply of nutrients, the sources of which are most likely agricultural fertilizer, septic systems, and livestock waste. Minor amounts of nitrate can be expected in unpolluted groundwater, due to nitrogen fixation by plants. Chloride levels, which were also higher than would be expected, ranged from 1.5 mg/l to 69.5 mg/l. Such levels are probably due to organic wastes from septic systems and livestock.

The spring-water quality indicates widespread karst groundwater contamination due to urban runoff, agricultural practices, and rural waste disposal. Some pollution is avoidable. Many rural residents employ no private waste treatment, but simply pipe household and septic waste into sinkholes. Nutrients supplied by agricultural practices are less avoidable. As long as row-crop farming is employed in the study area, some unavoidable fertilizer and agricultural chemical runoff must be expected. The high levels of suspended sediment in spring water, especially after rain storms, are due to two factors: row-crop farming, which allows soils to be more easily eroded, and the very open spring systems, which allow sediment to be transported.

RECHARGE AREAS OF SPRINGS AND RESURGENCES IN THE STUDY AREA

In general, dye-tracing studies are used to determine the source area of recharge to a given spring. In this study, the rational was slightly different: to determine which spring receives recharge from a given area. The major purpose of the study was to determine the directions of shallow groundwater movement in and and near the city of Perryville. Dye-injection points were certainly not selected at random; they were based on location, recharge importance, and other factors, including each site's response to runoff. City of Perryville officials were interested in several sinkholes used as dye-injection points, because of current or proposed construction activities, or because an individual sinkhole had a history of drainage problems.

During this study, 20 successful dye traces were made; an additional trace was run by cavers several years ago. Using dye-trace data and other geologic and hydrologic data it is possible to construct a recharge-area map for the study area. Nearly all dye traces originated within a 4-mi^2 area in and near Perryville. In almost any other part of the Ozarks, such detail would be superfluous. The subsurface drainage system in the Perryville karst area is quite complex, however, and even with the amount ofdye-trace data recovered it is impossible to delineate recharge areas completely accurately. Moreover, such accuracy is impossible unless a dye trace is run from every possible recharge site in the area -- an unlikely task. It further complicates matters that dye injected at one location may resurface at several different springs and resurgences.

Potentiometric maps are commonly used for defining directions of groundwater movement. Such a map is simply a contour map of water-surface elevations in wells open to a particular aquifer. A potentiometric map constructed for the study area, using wells open to the St. Peter Sandstone and

Joachim Dolomite (fig. 17), shows a prominent groundwater high about 2 mi north of Perryville and radial flow from that area. In karst areas, potentiometric maps are often misleading or even erroneous because they do not take into account subsurface conduits or the fact that a well-defined water table may not be present.

Figure 18 shows recharge areas of springs in the study area, based on the results of this study.

The primary springs that receive recharge from the city of Perryville are Doc White Spring and Mertz Resurgence. Thirteen of the dye traces ran to both springs; eight of the thirteen also ran to Circle Drive Resurgence. Before this study, it was believed that Mertz Resurgence was a major discharge point for the city of Perryville, based on previous work by cavers and existing geologic information. The importance of Doc White Spring, however, was not recognized, nor was the significance of Circle Drive and Heberlie Resurgences. Mertz Resurgence is known to drain two cave systems: Crevice Cave and Mertz Cave. Crevice Cave is almost entirely north of Perryville. Mertz Cave (fig. 19) forms a link between Mertz Resurgence and Crevice Cave. Only a few hundred feet separate the two caves, but the passage is water filled. The same conditions exist between Mertz Cave and Mertz Resurgence; a short distance of water-filled passage separates the cave from the spring outlet (fig. 20).

After the first dye trace, during which dye injected in a single sinkhole (Jerry Lawrence Sink) resurfaced at Circle Drive Resurgence, Doc White Spring, and Mertz Resurgence, the true complexity of the subsurface drainage system was revealed. There are at least two possible explanations for the multiple dye-recovery points. In one case, the nature of the groundwater system is such that subsurface flow divides, either vertically or laterally, thereby allowing flow to two separate outlets. Such a system could be considered a subsurface losing stream. Alternatively, the direction of groundwater movement could be controlled by the stage of the cave stream. Both ideas have merit and both are partly correct. The recharge of Circle Drive Resurgence is controlled by groundwater stage. It does not have a recharge area separate from Doc White Spring and Mertz Resurgence; instead, discharges overflow from the Doc White Spring-Mertz Resurgence recharge area in the northwest part of Perryville. The groundwater-flow system, like a surface stream, can only accept and transmit a given amount of runoff in a given time before the capacity of the system is exceeded. In the case of a surface stream, the excess water leaves the stream channel and flows across the flood plain. In the Perryville karst groundwater system there is no flood plain, of course, so when the capacity of the cave or conduit is exceeded, water level rises and water flows through higher fractures and openings, possibly the remnants of an earlier active groundwater conduit system. Figure 21 is a cross-section from Jerry Lawrence Sink to Dry Run Branch Estavelle and illustrates how changes in rainfall affect the directions of shallow groundwater movement.

Initially, Doc White Spring was believed to be a perennial groundwater outflow point; later it was discovered to be intermittent. The relationship between Doc White Spring and Mertz Resurgence was not completely understood until July, 1984. As mentioned in a previous section, numerous dye traces ran to Doc White Spring and Mertz Resurgence, both of which flow into Cinque Hommes Creek but are 6200 ft apart. Doc White Spring is also 80 ft higher than Mertz Resurgence. All other major springs and resurgences in the study area are along major streams and are at or very near stream level. On July 2, 1984 a dye trace was run from a small sinkhole a few feet from Doc White Spring to Mertz Resurgence. Doc White Spring was not flowing, but water was flowing across the base of the sinkhole, through small bedding-plane openings. Dye traveled in less than a day to Mertz Resurgence. It is now reasonably certain that Doc White Spring is an overflow outlet of the conduit system linking the karst area in Perryville to Mertz Resurgence (fig. 22); the map of Mertz Cave shows more evidence of this. Dye-recovery packets placed in the stream in Mertz Cave recorded the passing of the dye placed in the sinkhole at Doc White Spring. Mertz Cave has a mapped length of about 11,000 ft. Old Mertz Cave, the area downstream from the entrance, is easily accessible and contains large passage with ceiling heights of up to 40 ft. New Mertz Cave, the area upstream from the entrance, is much less accessible, with smaller passage dimensions, and it must be entered through several hundred feet of deep water and low ceilings. About 2100 ft upstream from the entrance, the trend of the cave passage shifts from southwest to northwest. Where the trend changes, a side passage enters; it is nearly water-filled and, according to notations on the map, much water enters there (Coons, et al., 1974). On the map, this inflow point is the only major water entry except for another siphon several thousand feet upstream, where water from Crevice Cave is thought to enter. The point where water enters from the side

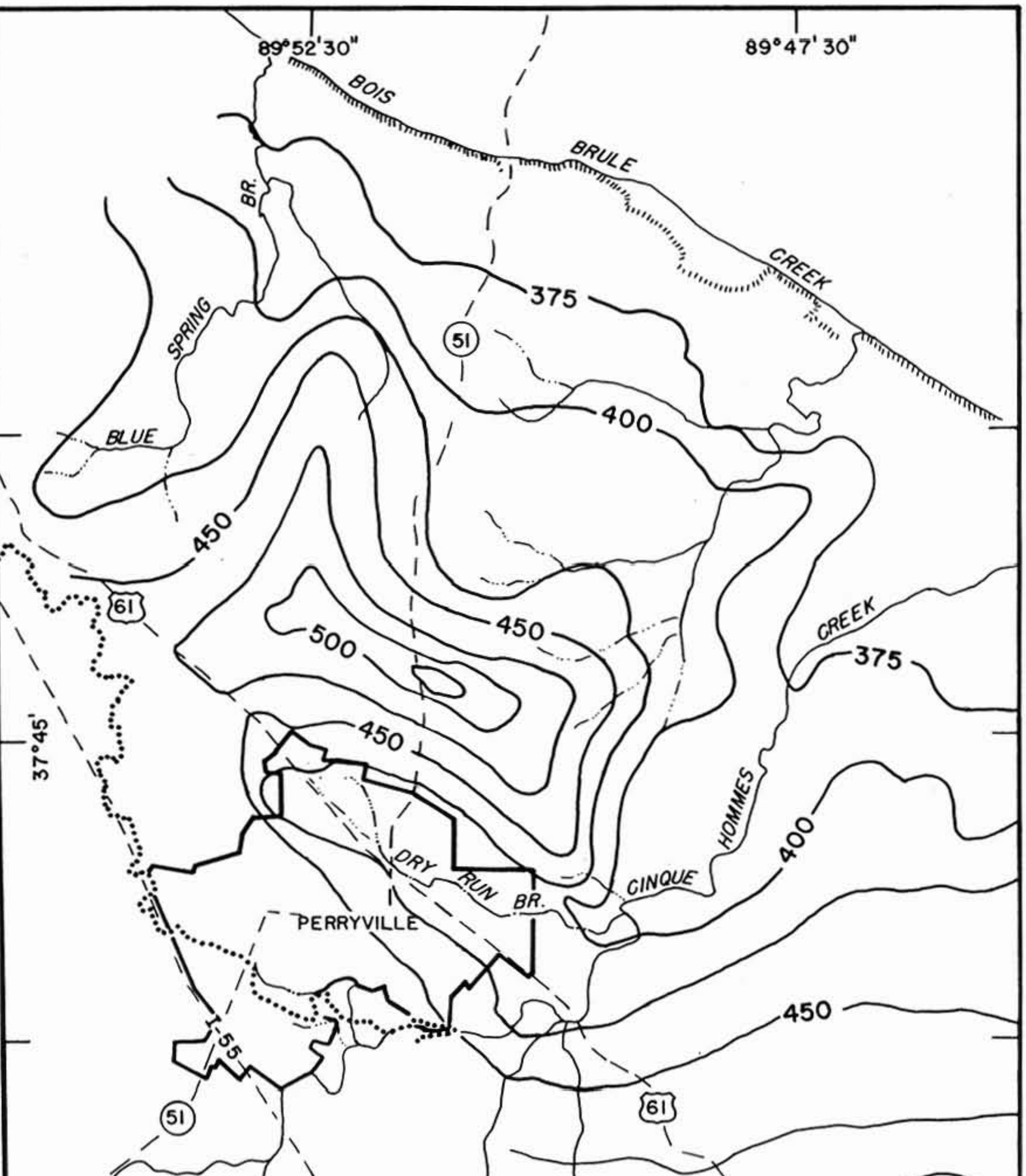


Figure 17 -- Potentiometric map of the shallow (Joachim Dolomite-St. Peter Sandstone) aquifers.

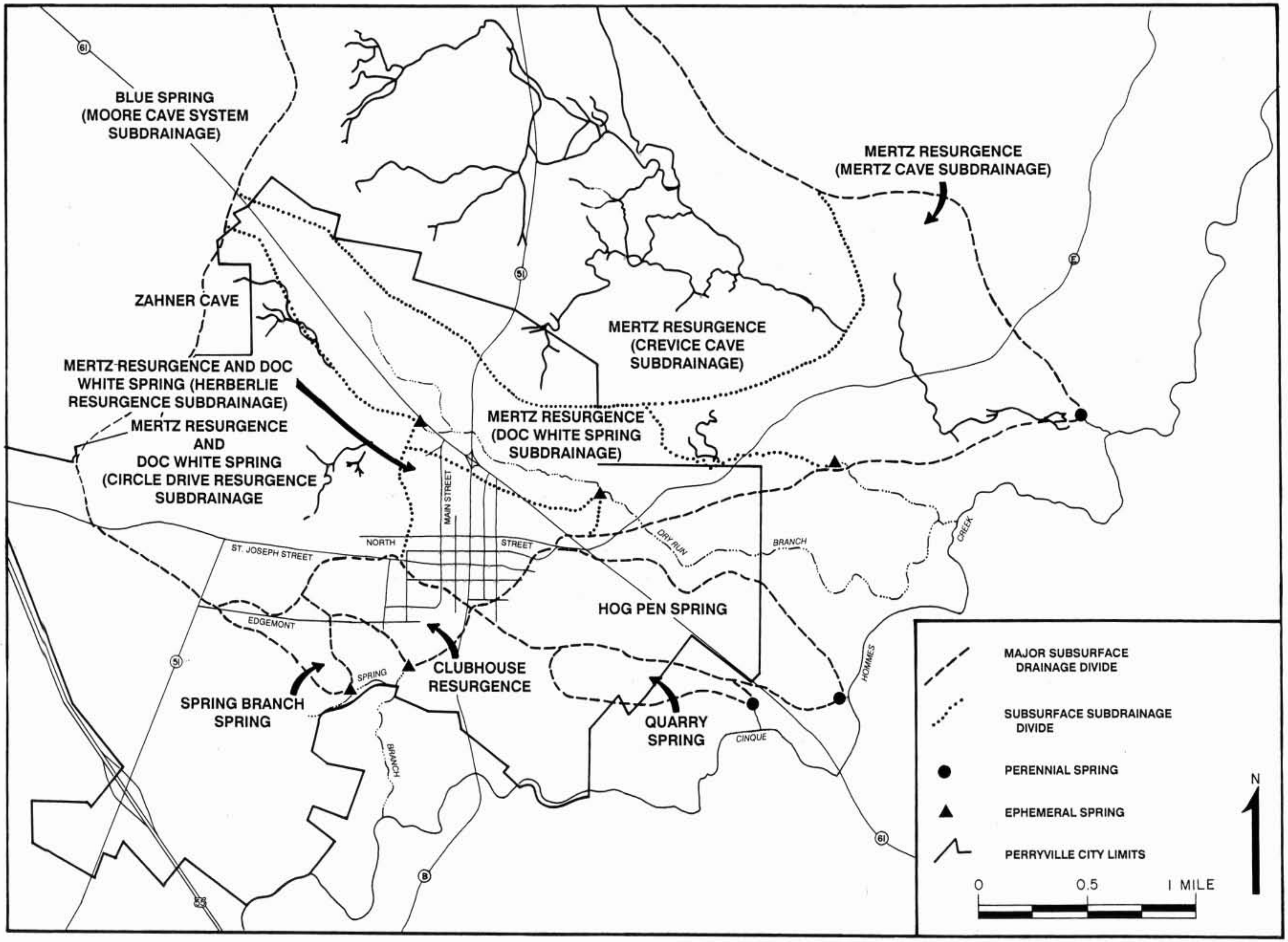


Figure 18 -- Recharge area map for major springs and resurgences.

Figure 19 -- Breakdown rubble in the entrace area of Mertz Cave.

passage of New Mertz passage is only 2200 ft from the sinkhole at Doc White Spring. Water flowing past Doc White Spring probably enters Mertz Cave at this point. In addition, Crevice Cave is probably not a drainage path for water entering the groundwater system in the city of Perryville, at least on the south side of Dry Run Branch. These conclusions are based on dye recovery at both Doc White Spring and Mertz Resurgence, on all dye traces to Mertz Resurgence. Supportive evidence is also provided by an earlier dye trace, made by cavers from Southeast Missouri State University, who injected dye into the stream of Klump Cave, 3500 ft northwest of Doc White Spring. Dye-recovery packets were placed throughout the down-stream part of Crevice Cave and in Mertz Cave. Dye was recovered in Mertz Cave but not in Crevice Cave (Scott House, 1984; pers. comm.). Based on those dye traces, it is concluded that a major conduit system probably exists beneath the karst area between Mertz Cave and the city of Perryville.

The recharge area for Mertz Resurgence can therefore be considered to have at least two major parts: (1) a northern portion, which is drained through Crevice Cave and which consists of the karst area overlying Crevice Cave, and (2) the area draining into the southern conduit system, which enters Mertz Cave downstream of the terminal siphon and extends into the city of Perryville. This is not to say, however, that cave passage of dimensions similar to Crevice Cave links Mertz Cave with sinkholes in the city of Perryville. This part of the groundwater flow system has not been entered, but the size of the conduit or conduits is large enough to transmit large quantities of water.

At least two separate subdrainages of Mertz Resurgence are in the city of Perryville: Circle Drive Resurgence subdrainage and Heberlie Resurgence subdrainage. Several caves are associated with Circle Drive Resurgence subdrainage. Zahner Cave, in the northwest part of Perryville, consists of about 1.9 miles of southeast-trending passage that terminates about 2000 ft from Circle Drive Resurgence. Streiler City Cave, North Street Cave, and Waters Street Cave, all in the Jerry Lawrence Sinkhole area in

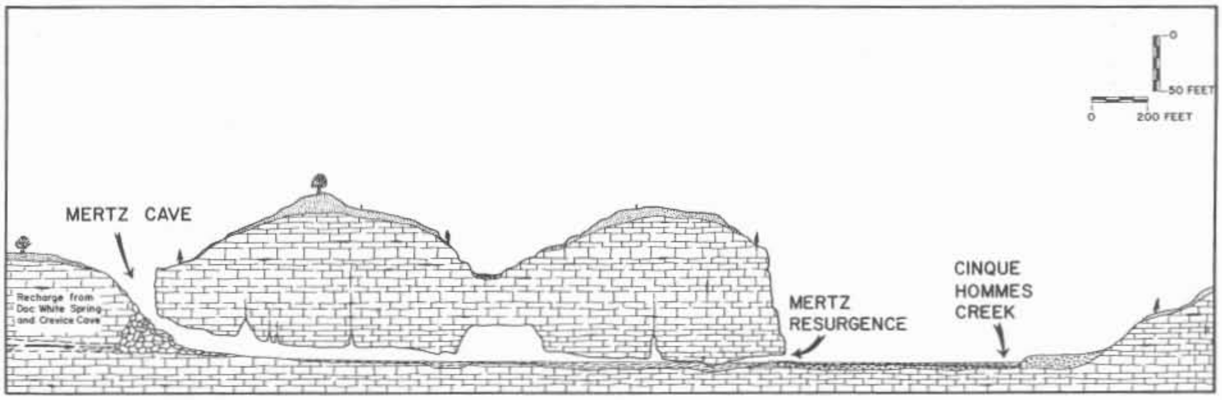


Figure 20 -- Diagrammatic longitudinal section of the lower part of Mertz Cave and Mertz Resurgence.

northwestern Perryville, are remnants of a single, now partly collapsed, cave. The downstream portions of Streiler City and Waters Street Caves terminate near a large sinkhole about 1500 feet from Circle Drive Resurgence. The cave through which Circle Drive Resurgence flows is only enterable for a short distance before it siphons. Though human entry is thwarted, water can exit. The elevation of the resurgence is about 520 ft mean sea level (msl). Accurate elevation data are not yet available for Zahner or Streiler City Cave, but elevation of the cave floor at the downstream terminus of Streiler City Cave is estimated at 525 feet msl. Dye traces have linked Zahner Cave, Streiler City Cave, and North Street Cave to Circle Drive Resurgence, but Circle Drive Resurgence discharges water only after moderate or heavy rainfall. Cave streams in Zahner Cave and Streiler City Cave have better sustained flows than Circle Drive Resurgence. Openings must therefore exist to channel water into a deeper conduit system. When the capacity of the deeper system is exceeded, water levels will rise and the excess water will discharge at Circle Drive Resurgence.

All but five of the Doc White Spring-Mertz Resurgence dye traces were also linked to Circle Drive Resurgence. Dye from the Oster Sink trace and the Zeno Street Sink trace were detected in the stream of Streiler City Cave. Jerry Lawrence Sink trace, Zahner Cave trace, Zahner Sink trace (repeat), School Street Sink trace, and Rozier Sink trace, and Rob Roy Sink trace all showed dye emerging from Circle Drive Resurgence during high-recharge periods. Dye from Ste. Marie Street trace, Parking Lot Sink trace, and Great Perry Cave trace was not detected at Circle Drive Resurgence. Presumably, these may flow through a different system, which enters the Doc White Spring-Mertz Resurgence conduit system downstream from Circle Drive Resurgence. Heberlie Resurgence, an intermittent spring on Dry Run Branch about 1000 ft upstream from Route E, is probably the overflow outlet for this subdrainage, just as Circle Drive Resurgence is for the area to the northwest. Two dye traces, Ste. Marie Pit trace and Great Perry Cave trace, substantiate this.

Throughout most of this study, Dry Run Branch Estavelle was believed to be only a recharge feature. Observations and a single dye trace indicate that the estavelle, though hydraulically connected to Circle Drive Resurgence, Doc White Spring, and Mertz Resurgence, does not receive recharge from the same area that recharges Circle Drive Resurgence (fig. 23). The Hospital Sink trace showed that the estavelle is recharged from an area south of Circle Drive Resurgence recharge area. When running the Hospital Sink trace, Rhodamine WT dye from the Rob Roy Sink trace was discharging from Circle Drive Resurgence. Dry Run Branch Estavelle was discharging water, but the Rhodamine was not detected in it, only fluorescein from the Hospital Sink. Fluorescein recovered from Heberlie Resurgence indicates it is hydraulically associated with the estavelle, which flows so briefly and infrequently that it is difficult to study.

Figure 18 shows the recharge areas for Doc White Spring, Mertz Resurgence, and associated subdrainages in the study area. The western limit of the recharge area, in the Sycamore Road vicinity, is based on the Zahner Sink dye traces. A trace from Zahner Sink, adjacent to Sycamore Road made during relatively normal weather, showed water from the sinkhole flowed to Blue Spring on Blue Spring Branch. The trace was repeated later, after very heavy rain,

and dye was recovered from Blue Spring and Circle Drive Resurgence, Doc White Spring, and Mertz Resurgence. Dye placed in the stream of Zahner Cave, only a few hundred feet from Zahner Sink, was recovered at Circle Drive Resurgence, Doc White Spring, and Mertz Resurgence, but not at Blue Spring. The recharge area boundaries are based on dye-trace data, cave maps, and surface karst topography.

Hog Pen Spring drains a portion of southeastern Perryville. Dye from only one trace was recovered at Hog Pen Spring. The dye was injected in a sinkhole in Perryville City Park, along Highway 61. Figure 18 shows the probable recharge area of Hog Pen Spring. It includes only a small part of the city of Perryville and the karst area east and south of the city, south of Dry Run Branch. One dye trace linked Quarry Spring with its recharge area. The dye was injected into a sinkhole near the southeastern edge of Perryville. The spring has a small but well-sustained base flow, but its peak flows are not proportionally as large as most of the other springs and resurgences, a condition that perhaps indicates a small recharge area, with a less-developed conduit system that allows groundwater to be stored between periods of recharge and released slowly. The recharge area is believed to be very limited and close to the spring, and borders Hog Pen Spring recharge area.

Two dye traces linked Clubhouse Resurgence to its recharge area. The spring drains a portion of southern Perryville. Based on observed flow characteristics, its recharge area is quite limited in size; it is shown in figure 18.

It is believed that Spring Branch Spring received dye from one trace, because dye injected in a sinkhole along the south side of Edgemont Blvd. was traced to Spring Branch, upstream from Clubhouse Resurgence. Dye-recovery packets were not placed in Spring Branch Spring, but dye was detected at the first bridge downstream of Spring Branch Spring. Later in the study, a new spring and resurgence were discovered in the upper part of Spring Branch watershed. Richardet Spring and Resurgence are only a few feet lower than the dye-injection site; they may have received the dye, but it is doubtful. Spring Branch Spring's recharge area is less karstified than most of Perryville; only a few surface sinkholes are present. In addition, its flow is less-sustained than Clubhouse

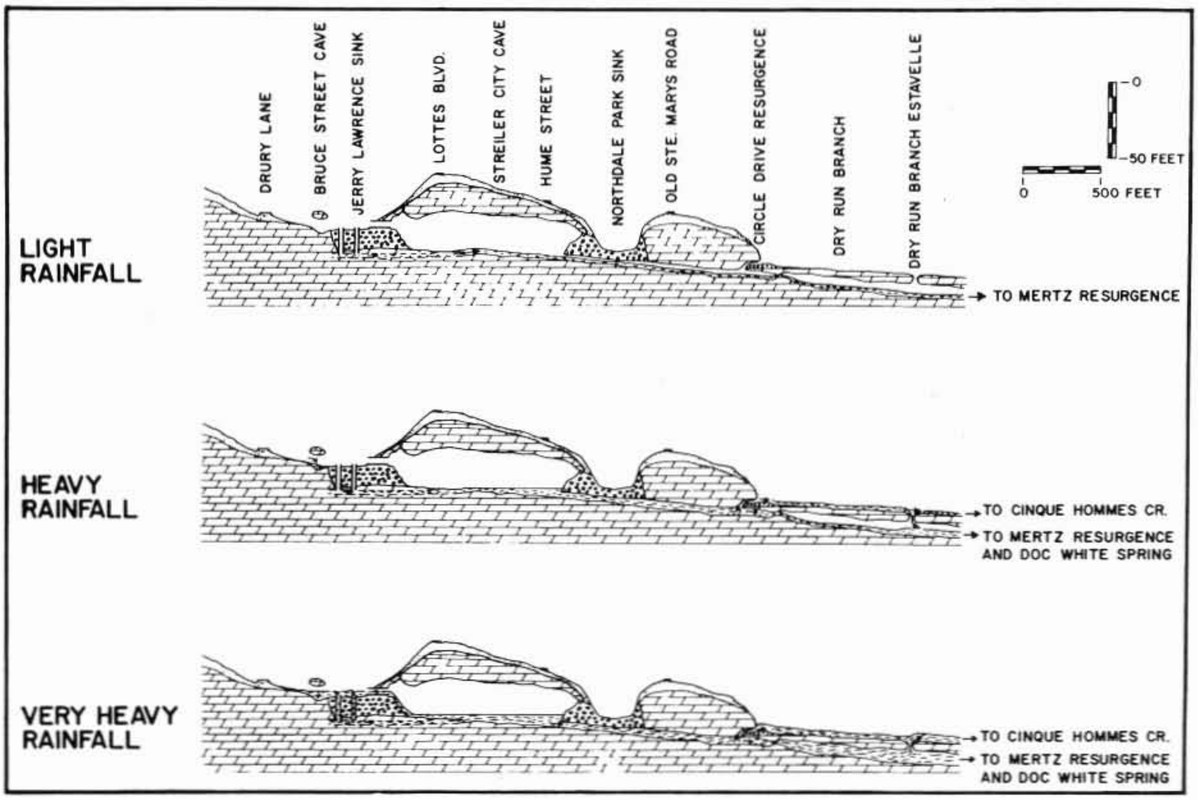


Figure 21 -- Diagrammatic cross-section of northwestern Perryville, showing hydrologic relationships of several karst features.

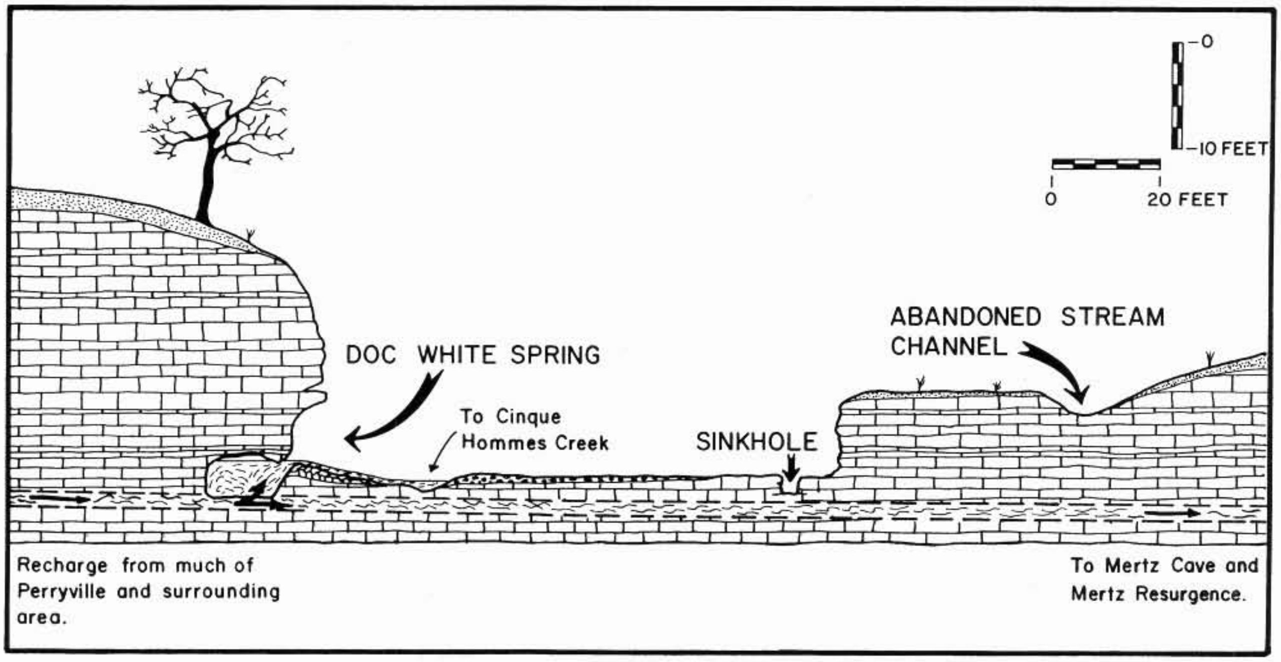


Figure 22 -- Diagrammatic cross-section of Doc White Spring, looking north-northeast.

Resurgence, and the spring does not flow during dry weather. The recharge area of Spring Branch Spring is shown in figure 18.

Two dye traces, both from the same sinkhole, show that Blue Spring, and during very wet weather, Blue Spring Resurgence, are recharged by the area south of the spring. Most likely, Blue Spring's recharge area overlies the Moore Cave System and includes the sinkhole area west and south of the cave system. Runoff from the city of Perryville probably contributes no flow to the spring, but a number of homes along Highway 61, northwest of Perryville, that have no central sewage treatment probably are causing karst groundwater-quality degradation in the cave system and at Blue Spring.

Keyhole Spring, Keyhole Resurgence, Ball Mill Spring, and Ball Mill Resurgence are not receiving recharge from the city of Perryville. They are most likely recharged from the karst area east of the Moore Cave System, on the south side of Blue Spring Branch, but the recharge areas were not established in the study.

EVOLUTION OF KARST DEVELOPMENT IN THE STUDY AREA

The purpose of this study was to determine the directions and rates of shallow groundwater movement in and adjacent to the city of Perryville. The history of the karst system development was not included as an objective, but much information containing clues to the evolution of the karst drainage system was collected during the dye-tracing study. Perhaps it is not directly important to know how and when karst developed, but knowing would help answer many questions about the complexity of current karst groundwater movement in the area. The following discussion is an attempt to combine the information gained in this study with previous work by geologists and cavers. It is premature, however, to claim that all questions concerning evolution of the karst can now be answered. The following ideas are based partly on conjecture and, because water is primarily responsible for the formation of karst, rely heavily on hydrologic evidence.

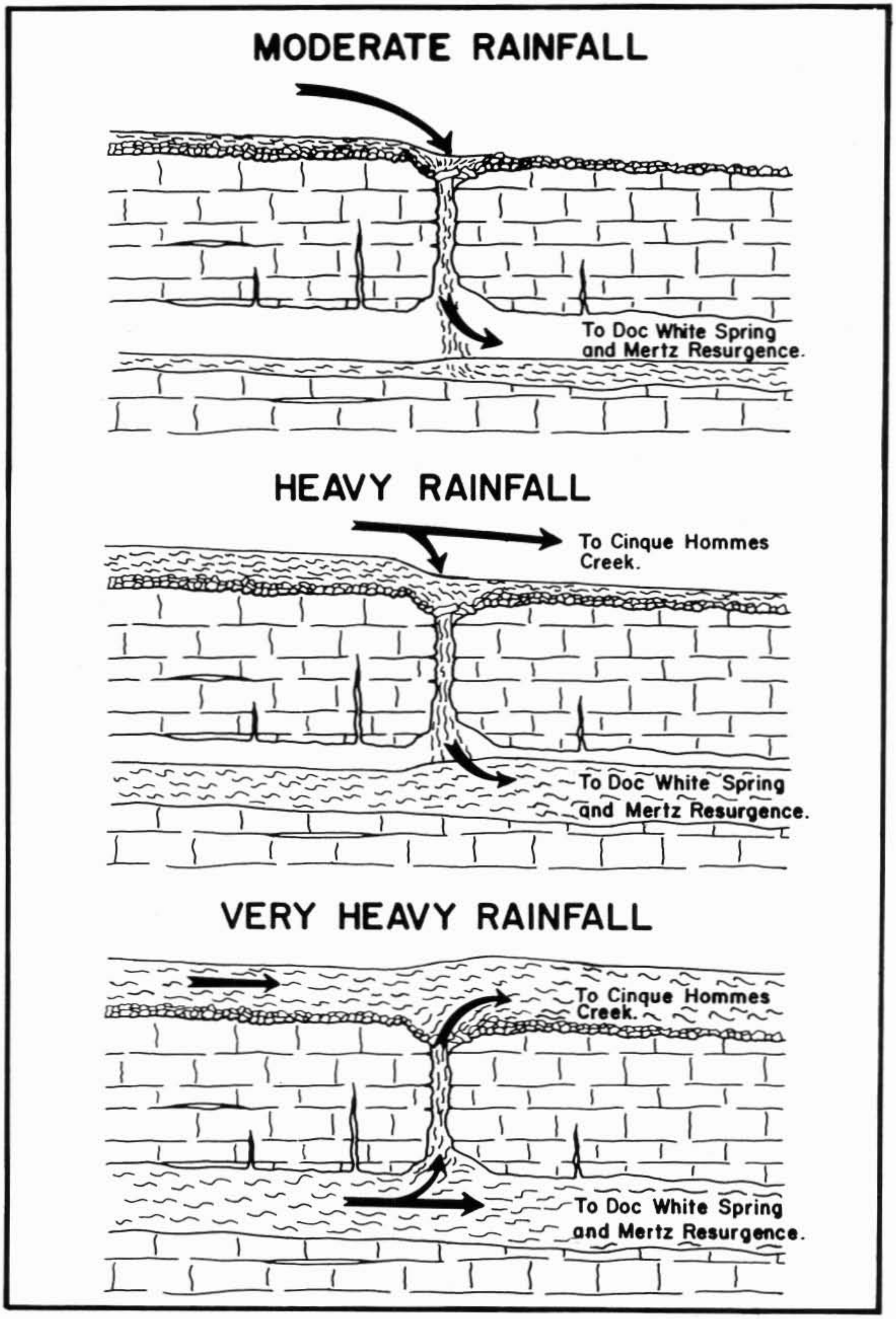


Figure 23 -- Diagrammatic longitudinal section of Dry Run Branch Estavelle.

One approach to determining the age of karst development is to estimate the time needed for karst to develop. Reams (1968, p. 78-83) presents an analytical approach for estimating this, based on the amount of dissolved solids in spring water and flow data for a large spring system, which is essentially a cave evolving under phreatic conditions. Using speleological data for the Meramec State Park area, he estimated 4 mi of cave passage were present for each square mile of surface area and assumed the cave passage to be 10 ft in diameter and cylindrical. For Maramec Spring, in Phelps County, Missouri, he calculated the spring system would evolve in about 1.3 million years, assuming one percent of the total dissolved solids contained in the spring water was derrived from cave formation and that the spring system had discharged at least 10 percent of the current average discharge throughout its history.

Reams' calculations seem reasonable for the 16-mi^2 Perryville karst area, which contains at least 45 mi of cave passage and probably considerably more. The cave passage density is at least 3 mi of passage per square mile of surface area. Groundwater recharge in the Perryville karst area is even greater than Maramec Spring recharge, and water quality is similar. If Reams' arguments are accepted, then the Perryville karst could have developed during the last 1.3 million years.

Several workers believe that the karst in Perry County developed sometime during the Pleistocene Epoch, which began some 1.8 million years ago and ended about 10,000 years ago. In Missouri, continental ice sheets advanced over parts of northern Missouri during the Nebraskan and Kansan Glacial Stages. During the Nebraskan, the ice sheet did not reach as far south as the present Missouri River. Ice advances during the late Kansan Stage ended at about the present Missouri River valley. The Illinoian Stage represented a third major glacial advance, during which glaciers extended further south, not in Missouri, but in adjacent Illinois. During the early Illinoian, glacial ice probably entered southeast Missouri but probably did not extend west of the bluffs along the flood plain of the Mississippi River.

Karst development is the product of dissolution of carbonate rocks. Primary cave development generally occurs under phreatic conditions, where groundwater saturates the rock units being solution altered. Solution most commonly occurs along rock fractures and along bedding planes separating successive rock layers. The water table, a planar surface dividing the saturated, or phreatic, zone, below which the rock is saturated with water from the upper vadose, or unsaturated, zone, is typically controlled by the elevation of major rivers and streams and by the hydrologic characteristics of the aquifers, or water-bearing units. During the Pleistocene. the ancestral Mississippi River probably influenced the water table in the study area even more than today. When the karst of Perry County was forming, the area water table was higher than today, due to several factors. Variations in Pleistocene climate and glacial processes caused fluctuations in the amount of river discharge and sediment load. In addition, damming and back-flooding in the Mississippi, caused by ice lobes or ice floes, allowed sediment to settle out and raise flood plain levels. The net effect was periodic raising and lowering of the area water table. Another factor was the hydraulic characteristics of the carbonate bedrock. Limestone and dolomite unaltered by solution weathering have low permeabilities, which result in poor subsurface drainage and a water table surface that closely resembles the topographic surface. As dissolution progresses along fractures and bedding planes during the infancy of cave development, groundwater circulation and subsurface drainage improve.

Topography in the Perryville karst area was probably much different when the karst drainage system was evolving. During that time, the topography was probably low relief, but early in the cave-forming period, direction of shallow groundwater movement was aready established, the evidence for which is the integration of subsurface drainage and the gradients of cave streams. Early, well-defined directions of groundwater movement required controlling structures such as surface streams. Even during early karst evolution, Cinque Hommes Creek and Blue Spring Branch may have influenced the directions of groundwater movement.

A subterranean conduit system is another possible mechanism for controlling the direction of early groundwater movement. Knox (1976, p. 7) discusses the possibility of an ancestral Cinque Hommes Creek Cave that presumably followed a path similar to present day creek. In such a cave, the Doc White-Crevice-Mertz Cave System would have been a major northern tributary; Mystery and Rimstone River Caves would have been the southern counterparts. If an ancestral Cinque Hommes Cave did exist, it could easily have contained 100 mi of passage. Such an idea is not without merit. Groundwater moves through all these caves to Cinque Hommes Creek, and the cave resurgences are near Cinque Hommes Creek, at

roughly the same elevations. The main trunk of ancestral Cinque Hommes Creek Cave, if it did exist, has succumbed to surface and subsurface erosion.

The ancestral Mississippi River controlled local base level and, during early Illinoian time, groundwater levels were much higher, due to the elevated Mississippi flood plain and poorer groundwater circulation. Downcutting of the Mississippi River channel after glacial retreat lowered local base level and perhaps allowed ancestral Cinque Hommes Cave and its major tributaries to begin functioning as a subsurface drainage system, the spring opening of which was somewhere in or near the Mississippi River bluffs. Even if ancestral Cinque Hommes Creek Cave was present, a surface stream probably continued to flow, at least in places, down ancestral Cinque Hommes Creek. Cinque Hommes Creek Cave, however, could have also pirated the surface stream in the upstream reaches. A clue to this is a cut-off hill or "lost hill," on Cinque Hommes Creek, in sec. 29, T. 35 N., R. 11 E. This physiographic feature could have resulted from rerouting of the creek, which left the hill isolated, with Cinque Hommes Creek following its northern edge and Schawanee Springs Branch bordering the southern edge. It is also possible that ancestral Cinque Hommes Creek once followed the southern edge of the hill and that ancestral Cinque Hommes Creek Cave daylighted on the northwestern side of the hill and pirated the upstream reaches of the stream drainage. Certainly the cave, if present, could not have extended much farther west; the St. Peter Sandstone outcrop belt is only a mile upstream of the lost hill.

The ancestral Cinque Hommes Creek Cave theory is interesting but is unnecessary to explain the karst history. More likely, Cinque Hommes Creek was the primary control for direction of groundwater movement in the Doc White-Crevice-Mertz Cave system area. The surface stream could have developed while the subsurface conduits were developing.

The present-day physiography and the character of the caves in the Perryville karst area also give clues to the age of karst development, at least in a relative sense. In this connection, a comparison between the Perryville karst area and karst development in the Salem Plateau is helpful.

Two distinctive types of caves are in the Salem Plateau. There are the older, air-filled caves that are generally entered from valley walls; these vary from nearly dry caves that currently provide no drainage, to those with streams that still provide some groundwater drainage. The second category comprises water-filled caves that are active phreatic groundwater conduits; these are the caves which channel water to major springs. In relative age, the Perryville caves are between these two extremes. The major caves are active groundwater conduits but, except for a few places, are not under phreatic conditions. Their active groundwater flow routes indicate that the Perryville karst caves are relatively young.

The types of cave entrances and springs also indicate the Perryville karst is young. The entrances to the Perryville caves are quite different from those of the "older" Salem Plateau caves. Almost without exception, the caves in the Perryville karst are entered from sinkholes in the upstream cave reaches. None of the major caves can be entered from spring or resurgence openings. The opposite is true in much of the Salem Plateau; major caves in most of southern Missouri are entered along valleys where the cave streams exit the caves. Caves entered from valley wall openings are well above present-day base levels, the elevation or level below which little erosion takes place. The major Perryville karst area springs and resurgences are nearly at local base level and can be entered only when Cinque Hommes Creek, Blue Spring Branch, and the Mississippi River have lowered base levels by lowering their channels another few feet.

If it were assumed that the Salem Plateau karst once contained sinkhole development similar to the Perryville karst, it would date the Salem Plateau karst as much older than the Perryville karst. This assumes original sinkhole development was destroyed by headward erosion, leaving sinkholes mainly in the upland areas, along surface drainage divides.

Depth of cave development is quite variable. In the upstream reaches of the cave systems of the Perryville karst area, specifically in the city of Perryville, cave systems are quite near the surface. These upstream reaches correspond to the up-dip areas of the bedrock and, topographically, to the higher elevations. Points in several of the caves in the Perryville area, such as Streiler City Cave, North Street Cave, and Zahner Cave, have very thin ceilings; little earth material separates the land surface from the top of the cave passage. These caves daylight in shallow sinkholes at fairly high elevations; the same is true for the Historic and Pipistrelle entrances of Crevice Cave.

The sinkhole plain developed after initial cave development, when subsurface drainage paths had been established. Solution along fractures in the uplands opened joints and fractures, thereby allowing connections between the bedrock and soil mantle. Water descending through loess into the fractures, and upward stoping of the bedrock, facilitated sinkhole development, the shallow-sided sinkholes developing over time as more soil material in the sinkhole was removed and flushed through the cave systems. In places, cave roofs were too thin to support their own weight, and catastrophic collapses occurred.

The land surface was neither significantly nor deeply dissected before the sinkhole plain developed. Dry Run Branch, the only surface drainage extending a significant distance into the karst plain, is an interesting stream, the evolution of which presents a problem; it seems unlikely that the stream developed by headward erosion. Upper Dry Run Branch contains numerous sinkholes in and near its channel, so it is likely that at least part of Dry Run Branch formed due to some form of karstification.

The Perryville area caves are probably relatively young, but there is evidence of older subsurface drainage. The fact that Crevice Cave, the Moore Cave System, and other caves in the Perryville karst contain passages that no longer function as subsurface drainage paths, due to subterranean stream piracy, lends credence to more than one episode, or at least an extended period, of cave formation and modification.

Much of the karst in the Perryville area is part of the Doc White-Crevice-Mertz Cave system. Zahner Cave, Streiler City Cave, North Street Cave, Water Street Cave, and Bruce Street Cave are probably all upstream segments of what was originally the same cave; Circle Drive Resurgence is also part of the system. Water from all these caves flows to Mertz Resurgence. Crevice Cave drains the northern part of the system, and Doc White Spring conduit, the southern part. Water from both caves flows through Mertz Cave. Doc White Spring is really just an intermittent karst resurgence; it is only a window in a continuing karst drainage system. Dry Run Branch, at least in the upstream reaches, is a karst valley. In its upstream areas, it does not function as a surface stream. The surface water is pirated by a series of valley sinkholes and an estavelle, and channelled to and past Doc White Spring, through Mertz Cave to Mertz Resurgence. It is quite possible that upper Dry Run Branch was originally cave passage, its roof breached by erosion in the past. Circle Drive Resurgence may be a remnant of an ancestral Dry Run Branch Cave or one of its side passages. Doc White Spring branch shows signs of developing in the same manner. The area around and immediately downstream of the spring displays the characteristics of a collapsed cave passage. Pirating of a surface stream by the cave left an abandoned stream channel several feet above present level of the spring branch. It is doubtful that the cave ran directly to Cinque Hommes Creek. Remnants of the surface stream pirated by the collapse at Doc White Spring show that a surface drainage was established before the collapse.

In the upstream areas of the major cave systems, caves are slowly being destroyed by natural forces. Cave development in Perryville is shallow. Several hundred feet into Streiler City Cave one can hear activity on the surface. Construction work in Jerry Lawrence Sink and also along Grand Avenue shows that the broad, shallow sinks contain collapsed cave passage, which, in places, construction equipment followed, excavating trenches for drainage pipes. The original cave outline can be seen when the collapsed material is excavated; the walls and floor of the cave remain. In the Perryville area, sinkholes are often in a linear arrangement, possibly the result of a collapsed or partly collapsed cave.

Though shallow caves are being destroyed, cave formation continues in the Perryville karst. As long as groundwater continues to dissolve earth materials, the caves will continue to enlarge. The fact that water flowing through Zahner Cave and Streiler City Cave does not reappear at Circle Drive Resurgence, except after heavy rain, shows the presence of a deeper, probably younger conduit system. During dry weather, when water still flows through Zahner and Streiler City caves, the younger, deeper conduit can accept the flow, but after heavy rainfall, the older, higher conduit leading to Circle Drive Resurgence is needed.

This discussion has relied heavily on the presumed dominance of phreatic conditions in the development of caves. No doubt phreatic conditions were responsible for forming the original openings in the rock, but the active cave systems containing streams have been greatly modified by vadose water. Because all drainage in the Perryville sinkhole plain is subsurface, runoff must flow through the caves. The downstream reaches of all the major caves are subject to flooding after heavy rain. A trip through lower Mertz Cave is most instructional in showing the effects of the moving stream water. Sections of the

cave contain current scallops caused by turbulent water flowing through the passages. It is possible that after initial phreatic development, vadose development greatly changed the caves, especially in the downstream areas. Once circulation was established, much of the cave formation may have been by vadose groundwater.

There is good evidence that certain surface streams in the study area developed by cave collapse or other karst processes, specifically upstream Dry Run Branch and Doc White Spring Branch, but it is doubtful that all surface drainages, including Cinque Hommes Creek, originated from collapsed cave passage. Evidence supporting a collapsed ancestral Cinque Hommes Cave is not strong; there are no remnants such as natural bridges or tunnels. Water discharging from Mertz Resurgence flows through a complicated, well-integrated conduit system consisting of both air- and water-filled passages, which includes Mertz Cave, Crevice Cave, Klump Cave, Doc White Spring Conduit, Zahner Cave, Streiler City Cave, North Street Cave, Bruce Street Cave, Waters Street Cave, and others yet to be entered. Multiple groundwater outlets of a single karst drainage system function as overflow outlets; their dishcarges are controlled by location, amount of recharge, and stage of the groundwater system. The overflow outlets may be the remnants of somewhat older karst, but all indications are that the karst in the Perryville area is very young and could have developed during the Pleistocene. The older, now shallow caves are being destroyed by weathering and newer, deeper caves are forming.

Many pieces of the karst evolution puzzle are unknown; weathering has destroyed them or altered them greatly. Much work remains to be done. Entry into the supply system of Doc White Spring will yield valuable information as will further exploration of the caves underlying Perryville.

IMPLICATIONS OF THIS STUDY

The city of Perryville relies on the shallow groundwater system for disposal of stormwater runoff. Knowing the direction of movement and destination of the storm runoff entering the sinkholes is akin to knowing the location of storm sewer pipes and outlets in a city having a more conventional drainage system. Urban development causes changes in natural water movement. Runoff amounts and rates change, and in some cases it is possible to divert water from one spring's recharge area to that of another. Knowledge of the underground flow system will help developers, planners, and engineers, who can use it to plan adequately for changes in land use brought about by urbanization. Karst areas like Perryville are especially prone to shallow groundwater contamination from spills. Truck accidents, gasoline tank leaks, and pipeline breaks can allow contaminants to enter the shallow groundwater system quickly. The city now has the ability to predict accurately not only where, but also when, spilled materials will reappear. Several of the springs in the area are used for livestock water supplies. This study can prove invaluable in preventing poisoning of livestock and mitigating damage to aquatic life in the event of a spill.

Much information was gathered during this project but not all of the questions pertaining to the karst drainage system have been answered. Further dye tracing will be necessary to better define the boundaries between spring recharge areas and to better understand the function of Dry Run Branch Estavelle. With a now adequate conceptual understanding of the conplexities of the spring system, data refinement can be accomplished economically.

REFERENCES CITED

Bretz, J Harlen, 1956, Caves of Missouri: Missouri Geological Survey and Water Resources (now Missouri Department of Natural Resources' Division of Geology and Land Survey), v. 39, 2nd series, 490 p.

Coons, Don, and Little Egypt Student Grotto, Missouri Speleological Survey, 1974, Map of Mertz Cave, Perry County, Missouri: unpublished map deposited in Cave Files, Missouri Department of natural Resources' Division of Geology and Land Survey, scale 1:2400.

Flint, Richard Foster, 1925, A report of the geology of parts of Perry and Cape Girardeau counties: unpublished manuscript, Missouri Department of Natural Resources' Division of Geology and Land Survey, 247 p.

House, Scott, 1975, Report on Great Perry Cave, Perry County, Missouri: unpublished report deposited in Cave Files, Missouri Department of Natural Resources' Division of Geology and Land Survey, 1 p.

Knox, Ray B., 1976, Geologic history of Perry County - a brief summary of major milestones *in* Fall 1976 MVOR Guidebook, The Southeast Caver, v. 2, no. 3, p. 6-7.

Monroe, Watson H. (compiler), 1970, a glossary of karst terminology: U.S. Geological Survey Water Supply Paper 1899-K, 26 p.

Reams, Max W., 1968, Cave sediments and the geomorphic history of the Ozarks: unpublished Ph.D. dissertation, Washington University, Saint Louis, Missouri, 167 p.

Vineyard, Jerry D., and Feder, Gerald L., 1974, Springs of Missouri: Missouri Geological Survey and Water Resources (now Missouri Department of Natural Resources' Division of Geology and Land Survey), Water Resources Report no. 29, 267 p.

Weaver, Dwight H., and Johnson, Paul A., 1980, Missouri - the cave state: Discovery Enterprises, Dark Pathways Series, Book Four, Jefferson City, Missouri, 336 p.

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